DESIGN IN NATURE

T. Gamlen, West Hartlepool Photo.

Yours sincerely
J. Bell Pettigrew

DESIGN IN NATURE

Illustrated by Spiral and other Arrangements in the Inorganic and Organic Kingdoms as exemplified in Matter, Force, Life, Growth, Rhythms, &c., especially in Crystals, Plants, and Animals. With Examples selected from the Reproductive, Alimentary, Respiratory, Circulatory, Nervous, Muscular, Osseous, Locomotory, and other Systems of Animals

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THE CIRCULATION IN PLANTS, IN THE LOWER ANIMALS, AND IN MAN

There are few things in nature more wonderful or which display design in a more striking and interesting manner than the circulation. The term is generally applied in a restricted sense to the passage of the blood through the heart and blood-vessels in the higher animals. It, however, can be employed in a greatly extended sense to include the passage of nutritious juices, whatever their nature, in plants with or without vessels, and in the lowest animals with or without hearts and vessels. In its widest sense it embraces the simple transudation of fluids in living substances, and these fluids may be aqueous or aëriform, or partly the one and partly the other. There may be a circulation of gases, of fluids, or even of solid particles—of, in fact, whatever enters into and passes through and out of living bodies.

Two very important facts are to be noted in connection with the circulation, and they are equally inexplicable in the absence of a First Cause and design. The one is that the nutritious juices of plants and animals move at all: the other is that they move in specific directions, and not infrequently in opposition to the great law of gravitation.

The circulation, in its wider sense, is to be largely credited with the building up, the nourishing, the sustaining, and the purification of living things, whether plant or animal. It avails itself of all the forces of life, and many of the physical forces. While it manifests itself mainly in living things (plants and animals), it freely makes use of the forces of endosmose, exosmose, attraction, repulsion, capillarity, cohesion, adhesion, gravitation, &c. In its very widest sense, the circulation includes the perpetual flux of the gases, fluids, and solids of the universe as a working system.

The mechanism of the circulation may be of the simplest character, but it may also be involved and complicated to an almost inconceivable extent. Whether simple or complex, the means employed never fail to attain the end in view. The tissues of living plants and animals are, in every instance, arranged to facilitate the circulation of the materials which enter the bodies of plants and animals as pabulum, which traverse their bodies and add to their bulk, and which ultimately leave them as waste products. The primary object of the circulation is to bring to and take from, and the essential movements of the circulation are give-and-take, interrupted, rhythmic movements; that is, movements recurring at stated intervals. In plants, and in the lowest animals, fluids and gases circulate together. In the higher and highest animals, the nutritive juices and the air circulate separately; the former in the heart and blood-vessels, the latter in the lungs or their representatives. In such cases, the nutritive juices and air react upon each other in certain definite areas (external respiration). The aëration of the nutritive juices is necessary to the health of plants and animals alike, and this demand for air extends to every part of plants and animals (internal respiration). They breathe throughout their entire substance and at every pore—even the cells composing them do the same.

The simplest cell plants and animals, and the most complex ones up to man, are under the same laws as regards respiration. This consists of the interchange of oxygen and carbon dioxide (CO_2). "There are, at least, two principles on which animal cells obtain oxygen.

"(*a*) The air, or water containing air, is carried to the cells. This is the principle adopted in the lower invertebrates, as in sponges, and with regard to certain air-breathers such as insects.

"(*b*) The other principle is this, that an intermediary carries the respiratory oxygen from some more or less central localised or diffuse surface to the cells. This intermediary is the blood—an internal medium of exchange. The fluid part of the blood may carry the oxygen supply and remove the carbonic dioxide waste. This is the case in many of the invertebrates, and it reaches its highest development in the vertebrates. Hence in them the circulating and respiratory systems reach their fullest development.

"In most invertebrates the fluid part of the blood contains the nutritive substances and also the oxygen and

carbonic acid. In the vertebrates, the hæmoglobin of the red blood-corpuscles carries the oxygen from the gills or lungs to the tissues, whilst the CO_2 is contained in and carried chiefly by the blood plasma from the tissues to the gills or lungs" (Dr. Wm. Stirling).

Similar remarks apply to the nutritive process and digestion. The cells and cell tissues of compound animals are nourished virtually in the same way that cell plants and animals are nourished. Whatever the nature of the pabulum, it must ultimately be presented in a fluid or semi-fluid form, and air must have access to it either directly or indirectly, by a respiratory or a circulatory apparatus. The essential parts of the circulation, respiration, and digestion consist in the passage and interchange of fluids and gases. Plants and animals are very largely composed of water: even in man some 70 per cent. of his substance consists of water. Water and air in large quantities are absolutely necessary, not only to the well-being, but also to the very existence of plants and animals. Life and death are largely questions of water and air. All parts of plants and animals are constantly bathed with both, and the free circulation of water and air cannot be dispensed with; indeed in the case of air it cannot in animals be interrupted for more than a few minutes without producing suffocation and death. Water and air are more necessary to plants and animals than solids. Parched plants and animals are, in a way, in the vicinity of death, and, if the supply of air be cut off, death is inevitable. The breath is the life.[1]

The circulation, the respiration, and, within limits, the digestion, are integral and essential parts of what is virtually a common system, and are best considered together.

In all the phases of the circulation, the presence of air somewhere in the circulatory arrangements is a necessity. A right of way for nutritious juices and air is a fundamental provision in plants and animals at their inception, and at all stages of their histories. The arrangements for circulating nutritious juices and air in plants and animals present an infinite variety. In certain cases the nutritive fluids and gases spread through the bodies of plants and animals by an osmotic process very much as water passes though bibulous and porous substances. In such cases, there are no vessels and no hearts present. In other instances, the nutritive fluids and gases are confined within vessels, more or less perfect; their movements being largely due to osmosis, capillarity, adhesion, cohesion, gravitation, evaporation, &c. In a third set of cases there are perfect vessels with one or more pulsatile cavities, which act rhythmically at given periods. The third set of cases are provided with separate aërating structures in the shape of either gills, or of lungs. In a fourth set of cases there are not only vessels but highly complex hearts and an elaborate system of valves which compel the nutritive fluids to circulate in particular directions. In the fourth set, separate and highly intricate lungs are invariably present. There is a gradual rise in the number and complexity of the circulatory and respiratory structures till man is reached. In the lobster, the heart consists of one muscular cavity, in the fish of two, in the reptile of three, and in the bird and mammal of four. In the bird and mammal the heart consists of two auricles and two ventricles; the right side of the heart (right auricle and right ventricle) receiving and propelling the venous impure blood through the lungs, where it is aërated; the left side of the heart (left auricle and left ventricle) receiving and propelling the aërated pure blood through the body generally.

The circulation in the higher animals is described as double, that is, a circulation for the lungs (pulmonic), and a circulation for the body (systemic).

There are four sets of valves in the heart of the bird and mammal, and these are supplemented by a large number of similar structures in the veins. The heart in the bird and mammal is a highly complex, muscular organ; its ventricles being the most intricate and powerful muscles known. They have already been carefully described and figured, and are alluded to further on. Taken as a whole, the circulatory apparatus furnishes overwhelming proofs of a First Cause and design, the obvious "means to ends" (everywhere apparent) completely eliminating the element of chance. Plants and animals have no power to form any part of their circulatory or aërating or alimentary apparatus. The organs of the circulation are not the outcome of environment, irritability, stimulation, utility, habit, or natural selection. They are fundamental endowments supplied *ab initio*. They are essential to life in all its forms. While plants and animals cannot produce their organs of circulation, &c., neither can they regulate or control the passage of the nutrient fluids through them. All this is under creative guidance, and for the wisest and most obvious of reasons. The circulation goes on, waking or sleeping, day and night, from the cradle to the grave, and never wearies or halts. It forms the veritable stronghold of existence. The marvel, as already pointed out, is that fluids in living plants and animals move at all, and the marvel reaches amazement when it is stated that the fluids, in many cases, move of their own accord as apart from vessels, pulsatile cavities,

[1] "We speak of a distinction between air-breathers and water-breathers. If, however, we push the matter to its ultimate issue, we find that all our tissues—and equally those of plants—live in a watery medium; in us the fluid lymph which exudes from our capillary blood-vessels, and in plants in the sap. Thus we come upon what at first seems a paradox, but is not so; all our cells not only live in water, but they live in running water. They are bathed everywhere by the lymph which is the real nutrient fluid for our cells. Thus, in its final form, all respiration is actually aquatic. The process of internal respiration, besides other conditions, requires the presence of a certain amount of water. In fact, all vital phenomena require the presence of water." ("Breathing in Living Beings," by Professor Wm. Stirling—*Nature* for August 10, 1905.)

and hearts. The amazement is increased when it is explained that in the bird and mammal the two auricles open when the two ventricles close, and *vice versâ* so long as life lasts; the blood being not only guided in certain directions, but made to open and close the valves, sluices, or doors, through which it passes on its way to and from the tissues and organs which it feeds and depurates at one and the same time. To watch the blood threading its way through the capillary blood-vessels by the aid of the microscope in the web of a frog's foot, the tail of a tadpole, or the mesentery of a mouse, is one of the most fascinating sights in physiology. Not less interesting and instructive is the intra-cellular circulation in plants. The latter is, in some respects, the most mysterious of all. The inauguration of the circulation in the developing chick is a unique fact in biology. Words cannot adequately express at once the simplicity and complexity of the circulation in its entirety.

The circulation of the blood forms such an important factor in the animal economy that I feel I need offer no apology for treating it somewhat exhaustively. The heart, its nerves, blood-vessels, and valves, supply a theme of unusual interest not only to the anatomist and physiologist, but also to the physician, and general reader. In order to give an intelligible account of the circulation, and the apparatus by which it is effected in man, I avail myself of whatever collateral information is within reach. This leads me to describe at more or less length the circulation in plants, in the lower animals, and in the fœtus.

By adopting this method I hope to lead up to the complex circulation as it exists in man, by a series of steps which, when taken together, form a sort of royal road to the goal at which I hope ultimately to arrive. The time devoted to the journey will not be lost if I succeed in displaying the links (fearfully and wonderfully made) of a chain, on the integrity of which life, in the majority of cases, depends. In some cases we shall find only one link of the chain present; in others, two; in others, three; and so on until we arrive at a degree of differentiation and completeness which, while it commands the reverence, must elicit the admiration of every one who reflects. In the human circulation nearly all the links are present, and it is only by a knowledge of these, as they exist in the lower grades of life, that we can hope to put them in their proper places, when we come to generalise or sum up.

The number of the cavities of the heart depends to a certain extent on the nature of the respiration, and this in its turn modifies the temperature of the blood. In the fish, breathing is effected, and the blood aërated, by the gills; one cavity (the auricle) receiving the blood from the system, the other (the ventricle) forcing it directly into the gills, and, through them, indirectly into the system. In the serpent, breathing is effected, and the blood aërated, by the aid of lungs; two cavities (the auricles) receiving the blood from the lungs and from the system; one cavity (the ventricle) forcing it through the lungs and through the system. In the reptile, the circulation is of a mixed character, the arterial and venous blood blending in the ventricle of the heart. In the bird and mammal, the heart, as stated, consists of four cavities—two auricles and two ventricles; the auricles receiving the blood from the system and from the lungs, the ventricles propelling the blood through the lungs and through the system. This object is obtained by a cross circulation—the right auricle receiving venous or dark impure blood, the left auricle arterial or bright red pure blood; the right ventricle propelling venous or dark blood, the left one arterial or bright blood. The differentiation observable in the cavities of the heart is preceded by a similar differentiation in the channels and vessels through which the nutritious juices flow; the elaboration of the heart and vessels necessitating the presence of valves, which vary in number according to the complexity of the circulatory apparatus. "In the lowest organised plants, such as the fungi, algæ, &c., and in the lower classes of animals, as the polypi, actiniæ, and a great part of the intestinal worms, the nutritious materials are transmitted through their substance, without any distinct canals or tubes; while in the higher classes of plants, and in the medusæ, &c., among animals, vessels are present, but these are unprovided with any pulsatory cavities. In the articulated animals the vessels are still without any pulsatory cavities, but to make up for the deficiency the dorsal vessel itself has a distinct movement of contraction and relaxation." [1]

With regard to the valves, it may be stated that they are only found in well-formed vessels, and at the orifices of canals or cavities having a definite structure. They are so placed that they compel the circulating fluid always to move in the same direction. They are consequently not found in plants, for in these, as will be shown presently, the nutritious saps at one period of the year flow from below upwards, and at another, from above downwards. A cross circulation, that is, a circulation across the stem, and a circulation within the cells of the plant, are likewise to be made out. The valves vary in number and in the complexity of their structure. In the veins they usually consist of from one to four segments. In the arteries, as a rule, they consist of three segments.[2] In the heart the segments may vary from two to three, and to these as many intermediate segments may be added. The number,

[1] "Cyc. of Anat. and Phys.," art. "Heart." By Dr. John Reid, p. 577.

[2] The valves of the arteries in the mammalian adult are confined to the origins of the pulmonary artery and aorta. They are termed semilunar from the shape of their segments. It happens occasionally that only two segments are present, the number increasing at times to four. In such cases a segment may be absorbed or divided into two by disease. It ought to be observed that rudimentary valves are found in the umbilical arteries.

however, may greatly exceed this, for in the bulbus arteriosus of the American devil-fish (*Cephalopterus diabolus*) we find as many as thirty-six segments. The valves may be placed within comparatively unyielding structures, as the fibrous rings found at the beginning of the pulmonary artery and aorta of the mammal; or they may be placed within yielding and actively moving structures, as the bulbus arteriosus of the fish, and the base of the ventricles of the bird and mammal. In the former case the structure of the segments is comparatively simple, and their action to a great extent mechanical; in the latter case the structure of the segments is more complex, the segments being provided with tendinous cords (*chordæ tendineæ*) which vary in length, strength, and direction. The tendinous cords are necessary to restrain the action of the segments within certain limits, and to co-ordinate the movements of the segments with the movements of the structures within which they are placed—the bulbus arteriosus and ventricle opening and closing alternately. The forces engaged in carrying on the circulation increase in direct proportion to the number and complexity of the hearts, vessels, and valves, and the number and variety of the tissues to be nourished. It is with a view to reducing those structures and forces to their simplest expression, that I propose to treat the subject of the circulation comparatively. What is true of all the particulars is necessarily true of the general; and if we succeed in comprehending a simple structure, and in following a simple action, the knowledge acquired will greatly assist us in comprehending complex structures and combined actions. It is comparatively an easy matter to understand a purely mechanical act. Here the forces and resistances can be appreciated with something like mathematical accuracy. It is comparatively a very difficult matter to understand a vito-mechanical act, for in this case we are never exactly sure what is vital and what vito-mechanical. This is especially true of the circulation, where we have on some occasions to deal with rigid tubes and cavities, such as exist in plants, and which are incapable of receiving an impulse from within; while in others, we have to deal with flexible elastic tubes and cavities such as are found in animals, and which are not only capable of receiving an impulse from within, but of storing up the impulse or power communicated, and of expending it as required.

If to the foregoing we add that the action of muscles—which, in animals, are the chief motors in the circulation—is comparatively unknown, we conclude a list of difficulties which it will require time, patience, and perseverance to overcome. These difficulties were present in force to the ancients, as a brief *resumé* of the history of the circulation will show.

§ 86. Epitome of the History of the Circulation.

We are in the habit, and very properly, of attributing the discovery of the circulation of the blood to the illustrious Harvey. It ought, however, not to be forgotten that there were many pioneers in this field before Harvey. The Chinese, for example, believed that the circulation of the vital heat and radical humours commenced at three o'clock in the morning, reached the lungs in the course of the day, and terminated in the liver at the end of twenty-four hours. This was a very vague and visionary notion of the circulation, certainly; still, it embodied the idea of fluids circulating within the body. The first rational attempt at unravelling this great mystery was made in the time of Hippocrates and Aristotle. It consisted of a description, apparently from dissection, of the principal blood-vessels. Galen, towards the end of the second century, described the course of the blood-vessels in many of the lower animals, and appears to have known the structure and uses of the *foramen ovale* in the fœtus, and that the arteries and veins anastomosed. He was also cognisant of the fact that the arteries contained blood, and described them as arising from the heart; the veins, in his opinion, arising from the liver. He thought that the blood passed through the septum of the heart; and this is actually true of the heart of the serpent. Neither Hippocrates, Aristotle, nor Galen, however, was aware that the blood circulated—that is, started from one point and returned to the same point after making the circuit of the body. Galen believed that the blood simply oscillated; and it is a curious circumstance that in plants, and some of the lower animals, this is what actually occurs.

Mr. Herbert Spencer, for instance, states that in plants the saps ascend and descend in the same vessels, and that their movements are interrupted at irregular intervals. Johannes Müller, in like manner, affirms that in the leech the blood-vessels on one side of the body contract and force the blood into those of the other and opposite side, and that these in turn contract and force it back again, the blood being made to oscillate transversely across the animal. The celebrated Vesalius examined the subject of the circulation afresh in 1542. He pointed out the difference between the arteries and veins, and showed that the veins and the heart contained valves. He also explained that the arterial pulse depended upon the systole or forcible closing of the ventricles of the heart. Here was a decided advance. Servetus, that martyr to science,[1] had as early as 1531 actually described a pulmonic circulation. He says, Whereas, in the adult, the vital spirit (blood) cannot pass from the right auricle into the left, because of the imperforate nature of the auricular septum, it must go through by the lungs, where it is changed, that is,

[1] Servetus fell a victim to religious persecution, and was cruelly burned alive at Geneva in 1553.

undergoes a transformation by coming in contact with the vital spirit which resides in the air, after which it returns to the heart. Servetus expressed his belief that the pulmonary artery and vein had some other function than that of nourishing the lungs—an inference deduced from their comparatively large size.

Cæsalpinus, in 1583, described the pulmonic circulation more carefully than Servetus had done, and showed that he had some knowledge of a double circulation. Nor did the fœtal circulation, with its several peculiarities, escape the lynx eyes of the anatomists of the sixteenth century. Galen, as has been pointed out, had a knowledge of the *foramen ovale*. He had also a partial knowledge of the *ductus arteriosus*. The *ductus arteriosus* was carefully described by Fallopius, Aranzii, and Vesalius. The last observer likewise discovered the *ductus venosus*, which was figured by Fabricius and Eustachius. It was reserved, however, for the immortal Harvey to place the coping-stone on the magnificent edifice of the circulation, and to this philosopher we owe our knowledge of the circulation in its entirety, and as at present accepted. Harvey was the apt pupil of a celebrated master. He studied under the famous Fabricius of Padua, for the protracted period of six years, namely, from 1596 to 1602. Fabricius, although entirely ignorant of the circulation as subsequently developed and explained by Harvey, had, fortunately for Harvey, an intimate knowledge of the valves of the veins, of which he published an account in 1603. From Fabricius, then, the illustrious Harvey derived much of that information which enabled him to astonish the world by his brilliant discovery. Harvey, on his return to England, instituted a series of experiments with a view to determine the exact nature and uses of the venous valves. The inquiry was laborious, and long; and it was not till the year 1619, that is, seventeen years after he left Padua, that he ventured to teach the doctrine of the double circulation publicly. Other nine years elapsed before the *Exercitatio Anatomica de Motu Cordis et Sanguinis in Animalibus* saw the light. This celebrated work was consequently published in 1628, and, curiously enough, not in England but in Frankfort. It therefore took Harvey some twenty-six years to mature and perfect his views.

Harvey left little to be done, but that little fell to the lot of a worthy successor, the renowned Malpighi, who, in 1661, by the aid of the microscope, discovered the capillary circulation, and the presence of blood-globules within the vessels. Harvey's views, thoroughly matured, and sound in warp and woof as they were, met with a determined opposition, and it was only after many an unseemly conflict between really great men, that the blood was allowed to flow quietly in the double channel which he had taken such pains to discover and describe. There is little chance of its changing its course now; and the task which I set myself in the present part of the work is to point out the course which the blood and other nutritious juices pursue, as they meander about in the organic world, now free, now confined; now checked by the presence of valves, now hurried forward by the pressure of vessels, hearts, and other forces, to which I shall have occasion frequently to allude as the subject becomes more complicated.[1]

§ 87. Definition of the Circulation.

The term circulation, as already indicated, is employed in a restricted and in a general sense. In its wider signification it embraces the course of the nutritious juices through plants and the lower orders of animals; in its more limited signification, and as applied to man and the higher orders of animated beings, it indicates the course of the blood from the heart to the capillaries, and from these back again to the heart. The word circulation literally means a flowing round—a going and returning; and it is well to bear the original meaning in mind, as we shall find that a single circle aptly represents the circulation in most of the lower animals; a circle, with one or more accessory loops, representing the circulation in the higher ones. In man, the chief circle represents the systemic circulation—two accessory loops representing the circulation through the lungs and through the liver. The accessory loops may be increased indefinitely to meet the requirements of particular organs.

In order to obtain a comprehensive knowledge of the great subject of the circulation in its several phases, it is necessary to lay the entire flora and fauna under contribution, seeing there is a natural sequence in the units of the circulation as we rise from lower to higher forms; the more rudimentary plants and animals supplying the information required for interpreting peculiarities in the higher plants and animals.

It will be convenient to deal first with the circulation in plants.

[1] My researches on the circulatory apparatus and circulation date back to 1858, when I was a medical student at the University of Edinburgh. In that year I made an exhaustive series of dissections of the muscular fibres of the heart in vertebrates. In the year 1860 I made extensive dissections of the nerves of the heart. In 1864 I described the structure and explained (as the result of numerous experiments) the functions of the valves of the heart and blood-vessels, and, in 1872, I delivered a course of twelve lectures to the President and Fellows of the Royal College of Surgeons of Edinburgh, in their Hall, "On the Physiology of the Circulation in Plants, in the Lower Animals, and in Man." The investigations referred to were published during the years 1860, 1864, and 1872 respectively, and have, for the most part, furnished the data for the present part of the work. References to my published writings on these subjects are given elsewhere.

CIRCULATION IN PLANTS

In plants the circulation is in its most rudimentary form; in fact it is incomplete as a circulation, that is, as a continuous flow of nutritious juices in a circle. My meaning will be obvious when I state, that in trees the sap flows steadily upwards in spring, and steadily downwards in autumn. The chain is, as it were, broken at both ends. There is, in addition to the upward and downward currents, a certain amount of transfusion, that is, of cross currents running in the direction of the breadth of the stem; but the transfusion referred to is trifling when compared with the two principal, and, as regards time, interrupted currents.[1] In order to comprehend the true nature of this interrupted and, so to speak, disjointed circulation, it is necessary to remember that plants (trees, for example) have a season of activity and a season of repose; that they increase in an upward direction by means of shoots, in a downward direction by means of roots, and laterally by branches.[2] In other words, they increase in every direction; and this holds true of growing animals as well as growing plants. The shoots, by their upward growth, tend to draw up the sap; the roots, by their downward growth, to draw it down; and the branches, by their lateral growth, to draw it transversely. Here, then, are the materials for an interrupted or disjointed circulation with a certain degree of oneness about it. Nutrition is a principal factor in the process. The idea of a plant or tree increasing in an upward and downward direction and laterally at one and the same time, is consistent with fact. When a seed grows, it extends itself into the ground and into the air; that is, it spreads from a centre in an upward and outward direction, and in a downward and outward direction.[3]

Fig. 82.

Fig. 83.

Fig. 84.

Fig. 82.—A seedling dicotyledonous plant with an ascending and a descending axis (after Henfrey).

Fig. 83.—*Pandanus odoratissimus*, the screw-pine, with adventitious roots supporting the trunk (after Henfrey).

Fig. 84.—*Rhizophora Mangle*, the mangrove-tree, supported as it were upon piles by its numerous roots, which raise up the stem. The plant grows at the muddy mouths of rivers in warm climates (after Balfour).

If, bearing this fact in mind, it is remembered, that as the tree grows the central point from which it had its being moves upwards (it must do this if it is to maintain its central position with reference to the tree as a whole), then we are forced to conclude that the stem of the tree itself is sending off processes in an upward and downward direction, and likewise laterally. That the central or germinal point recedes in an upward direction as the stem grows is rendered almost certain by the researches of Henfrey, who has shown that the root in growing exercises an upward pressure as well as a downward one; and that if the upper part of the root be relieved from its load of superimposed earth, and the weight of the plant balanced, the root, in virtue of its elongation alone, will cause the whole mass of the plant to rise bodily upwards. This is particularly well seen in the mangrove-tree and screw-pine, where the stems are raised completely out of the ground, and supported as it were upon piles (Figs. 83, 84).

§ 88. Two Different Systems in Plants.

The embryo, according to Petit Thouars and Gaudichaud, consists of two portions, a caulinary and radicular; the one having a tendency to ascend, the other to descend. These portions, which may be taken to represent different systems, have different sets of cells and vessels; the ascending system in the dicotyledons being connected with the medullary sheath, and passing into buds and leaves; the descending system, which is situated between the sheath and the bark, being connected with the woody tissue sent down from the leaves. The woody fibres of the leaves, aided by the cambium, are developed from above downwards. This belief in a double system in plants

[1] "The nutriment fluids in plants follow certain directions according to the structure and arrangement of the tissues, the locality of the sources of nutrition and of growth, or other actions; and as regards the elaborated fluid, the movement may be—(1) from the place of formation to that of consumption; or (2) to the stem, cells, or reservoirs; or (3) from the latter to the place of consumption."—"Henfrey's Botany," as edited by Dr. Masters, F.R.S., p. 570.

[2] "The sap will flow to the several parts according to their respective degrees of activity—to the leaves while light and heat enable them to discharge their functions, and back to the twigs, branches, stem, and roots when these become active and the leaves inactive, or when their activity dominates over that of the leaves. And this distribution of nutriment, varying with the varying activities of the parts, is just such a distribution as we know must be required to keep up the organic balance."—"Principles of Biology," by Herbert Spencer, vol. i. p. 557.

[3] The hydrogastrum, one of the algæ, consists of a single cell, but this cell is so differentiated as to simulate a perfect plant, with roots, stem, bud, and fruit.

is confirmed by numerous facts, and in especial by the vascular bundles in palms, &c.; these bundles proceeding from the base of the leaves, and interlacing in a curved downward direction, as shown in Figs. 85, 86, and 87.

It is also confirmed by the development of aërial roots from different parts of the stems of screw-pines, tree ferns, vellozias, figs, &c.; the stem of the screw-pine actually becoming less in proportion to the number of adventitious roots given off (Fig. 83, p. 430). In some palms, moreover, the descending fibres burst through the stems externally and appear as roots. If further confirmation of this view were necessary, it is to be found in the fact that occasionally sound wood at a higher level of the stem sends down roots into rotten wood on a lower level. Mr. John Lowe gives a curious example of this in the *Salix viminalis*, a species of willow. The trunk decayed in the centre, and from the sound wood above the decayed part a woody root eighteen inches in circumference descended. It penetrated the rotten mass, and when it reached the sound wood beneath, gave off branches which reached the soil. The radicular stem ultimately produced leaf-buds and leaves. That two distinct, and in some respects opposite systems exist in plants, is rendered exceedingly probable by the researches of De la Hire, Darwin, Knight, Aubert du Petit Thouars, Gaudichaud, and Macaire; the last observer believing that even the roots of plants have a twofold function—the one to extract moisture from the soil, the other to return excess of moisture to it. The presence of two systems in plants, or what is equivalent thereto, is, in a measure, necessary to explain the phenomenon of their general circulation. Without some such arrangement it would be difficult to account for the ascent and descent of the sap, and, at certain periods of the year, the deposit, storage, and subsequent removal of starch corpuscles, the simultaneous increase of a tree by shoots, branches, and leaves in the air, and by roots and spongioles in the ground.

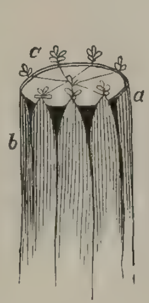


Fig. 85.

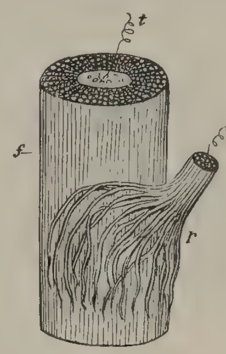


Fig. 86.

Fig. 87.

Fig. 85.—Slip or cutting of root of *Maclura*, showing a number of buds, *c*, from which proceed radicular fibres, *a*, which are interposed between the bark, *b*, and the fibres of the old wood. The young fibres are traced to the buds, and, in their progress downwards, they remain distinct. This example is brought forward by Gaudichaud as illustrating his vertical theory of wood formation (after Balfour).

Fig. 86.—Truncated stem of a *Dracæna* after maceration, showing the tracheæ, *t*, *t*, of the ascending system of the stem and branch. The radicular system of the old stem, *f*, is seen in the form of fibres, and the radicular woody bundles, *r*, of the branch are disposed in a grasping manner over those of the old stem. The fibres, according to Petit Thuaors and Gaudichaud, come from the bases of the leaves, and belong to the descending system (after Balfour).

Fig. 87.—Vertical section of the stem of a palm, showing the vascular bundles, *fv*, curving downwards and interlacing. This peculiar arrangement suggests the idea of roots ramifying (after Balfour).

§§ 89–90. Two Principal Sap Currents in Plants—Proof that the Saps Ascend and Descend.

The existence of two principal currents can be readily detected, for it is found that if a tree or its branches be notched in the spring, its sap flows in an upward and outward direction; whereas if notched in the autumn, the sap flows in a downward and outward direction. The spring and autumn correspond to the bleeding seasons of trees. Walker,[1] Burnett,[2] and others have shown that in trees there is no descent of sap until after the development of the leaves. This was ascertained by making triangular incisions into the bark and wood of trees in spring and summer respectively. From numerous experiments these investigators came to the conclusion that in all instances the spring sap begins to flow at the root, and that it rises slowly but surely to the very extremity of the tree. This was proved by the tree bleeding at the lowest notch first, and at the under side of the notch before the upper. It was further ascertained that the upward current extends from the stem to the branches. To these interesting experiments Mohl added another of great value. He showed that if a ring of bark be removed, the sap flows up as before the mutilation, but that if a portion of the wood be removed without injury to the bark which covers it, the part of the wood above the wound is no longer supplied with sap, and dries up.

A converse experiment was performed to prove the descent of the sap in summer. When a ring of bark is removed, the girth of the tree increases in volume above the injury, and remains *in statu quo* below the injury. If, moreover, as Henfrey states, bark be removed in patches, and the surfaces become gradually grown over by new wood, the greater part of the new growth comes *from the upper side*.[3] This shows not only that the crude sap ascends

[1] Walker's "Experiments on the Motion of Sap in Trees." *Trans. Roy. Soc. Edin.*, i. 3.

[2] Burnett, "On the Development of the Several Organic Systems of Vegetables." *Jour. Roy. Instit.*, vol. i.

[3] "In dicotyledons the elaborated sap descends in the fibro-vascular bundles of the cambium layer of the wood and in the internal tissue of the bark. It also passes inward by lateral transfusion. In dicotyledons the inner layers of wood generally become converted in course of time into *heart-wood*, the solidity of which obstructs the passage of fluids, which then ascend chiefly in the younger outward layers of the wood which constitute the alburnum or sap-wood."—Henfrey's "Botany," pp. 568, 569.

but that the elaborated sap descends, and that starch granules and other matters are stored up or converted into wood in the part above the injury. If the tree be cut in summer, the nutritious juices, owing to their greater viscidity and other changes, do not flow outwards. This shows that the nature of the circulation and the material circulated at this period is somewhat different from what it is in spring and autumn. In summer, the crude sap, which is absorbed by the roots, rises to the leaves, where, by evaporation and other processes, it is elaborated into the *succus proprius* or proper food of the plant. The *succus proprius*, which differs in its constitution from the crude sap, subsequently descends into the stem, through which it diffuses itself by a collateral circulation, to be stored up for future wants. M. A. Gris was convinced that the sap ascends and descends from finding that in winter the medullary rays, wood, and pith, are filled with starch grains, which disappear in a great measure during the spring, and are replaced during the summer. He was led to conclude that there are two special movements of the nutritious juices, as illustrated by the formation of starch granules in summer, and their absorption in spring. That the sap ascends there can be no doubt, for the plant derives its nourishment chiefly from the earth; and that it descends is proved by the experiments referred to. In spring the circulation is mainly concerned with the elongation of the stem and branches, the development of the buds, and the evolution of the leaves, its course being for the most part upwards.[1] In summer it is chiefly concerned with the functions of the leaf, the elaboration of sap, and the storing up of food for the plant, its course being partly upwards and partly downwards; while in autumn, owing to excess of moisture, a diminution of temperature, and other changes, the course of the circulation is for the most part from above downwards; the circulation having, so to speak, completed its work for the season. It may be well to state that the ascending current of spring is accompanied by a slight downward current, the descending current of autumn being accompanied by a slight upward current; the spring and autumn currents diffusing themselves as they go. This follows because of the share taken by endosmose and exosmose in the circulation. Much more sap is taken up than is given off in spring in order to administer to the growth of the plant. In autumn, when the period of growth is over, this process is reversed, more sap being given off by the roots than is taken up by them. The circulation in a tree, as will be seen, is interrupted or non-continuous, and this is accounted for by the tree having periods of greater and less activity. This holds true also, within certain limits, of animals; the circulation in animals being most vigorous when the animal is awake, or when excited; and least so when it is in a quiescent state, when sleeping, or when hibernating. I have attempted to convey an idea of the scheme of the circulation in plants by the aid of the subjoined figures (Figs. 88 and 89).

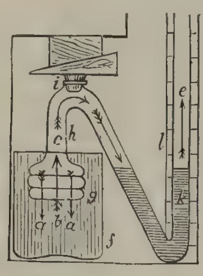


FIG. 88.

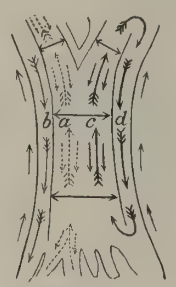


FIG. 89.

FIG. 88.—Endosmometer, showing endosmotic and exosmotic currents. *f*, Glass vessel containing water; *g*, expanded portion of glass tube bent upon itself at *i* and *k*, its under surfaces being covered by a piece of bladder; *k*, column of mercury. The space between the column of mercury and the bladder (*g*) is filled with syrup at aperture *i*. Immediately the water and syrup act upon the bladder or interposed membrane, opposite currents are induced, the water rising through the bladder and syrup with great energy, as indicated by the arrows, *b*, *c* (endosmosis), the syrup settling down into the water more feebly, as indicated by the arrows *a a* (exosmosis). The water sets towards the syrup with such force as to elevate the column of mercury *k*, in the tube *l*, in the direction *e*. In addition to the principal currents, indicated by the arrows *a* and *b*, there are minor currents which proceed transversely. These are best seen when the bladder is made to project beyond *g*, so as to display a certain amount of lateral surface (after Dutrochet).

FIG. 89.—Diagram, representing the ascending, descending, and transverse currents in the plant. *a*, Ascending or spring current; *b*, descending or autumn current; *c*, *d*, ascending and descending currents of summer, these being continuous in the direction of the leaves and roots; *a*, *c*, transverse currents. The arrows in this diagram represent the endosmotic currents, the darts the exosmotic ones (the Author, 1872).

In contemplating Fig. 89 we are at once struck with the diversity in the direction of the currents; one ascends, another descends, and a third runs transversely or at right angles to both. The ascending and descending currents are most strongly pronounced. These currents—and it is a remarkable circumstance—are found in all the higher plants and animals up to man himself. The object to be attained is manifest. The circulation is instituted expressly for the purpose of carrying matters of divers kinds to and from the tissues. But to give to and take from implies movements in diametrically opposite directions. In animals with hearts and blood-vessels supplied with valves, we can readily understand why the circulating fluids should pursue two directions, the one current setting from the heart, the other towards it; but in trees and animals without hearts the explanation is not so obvious. The descending current could readily be accounted for by gravitation; but gravitation can take no part in producing the upward current.

[1] To the progress of the sap in the direction of the axis in spring Burnett ascribes the early development and vigour of the terminal buds.

§ 91. Endosmose and Exosmose as Adjuncts of the Circulation.

Without a knowledge of the physical forces, the true nature of the ascending and descending currents in plants [1] would for ever have remained a mystery. Dutrochet,[2] however, made the important discovery, that if a watery or tenuous fluid be placed on one side of a membrane, animal or vegetable, and a thick or mucilaginous fluid on the other (the fluids having an affinity for each other, and for the interposed membrane), two counter or opposite currents are at once established, the thin fluid setting with a strong current in large quantity towards the thicker fluid, which it penetrates (endosmose); the thicker fluid setting with an equally well marked but more feeble current, and in smaller quantity, towards the thinner fluid, with which it in turn intermingles (exosmose). This mingling or diffusion of the fluids through each other occasions a multitude of minor, and what may be regarded as transverse currents (Fig. 88).

In endosmose and exosmose we have physical forces which bear the same relation to each other that the ascending, descending, and transverse currents of plants bear to each other. In fact we shall not be overstepping the limits of legitimate inference if we state that the forces of endosmose and exosmose form important factors in the circulation in plants, and work in the same direction or alongside the vital forces. The vital forces control the physical forces within certain limits to a desired end. From these remarks it will appear that the living plant takes advantage of existing forces when it grows or builds itself up; that, in fact, the plant has its parts arranged expressly with a view to availing itself of those forces; the living as it were arising out of the dead, according to fixed laws which govern alike the organic and inorganic kingdoms. It is this circumstance which enables the plant to reciprocate with the external world, and which in some senses fixes its place in nature. Very similar remarks may be made regarding the circulation in animals, inasmuch as in their ultimate tissues the advancing and receding currents referred to invariably exist.

FIG. 90.

FIG. 91.

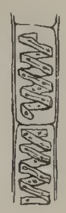


FIG. 92.

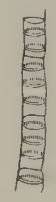


FIG. 93.

FIG. 94.

FIG. 95.

FIG. 96.

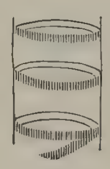


FIG. 97.

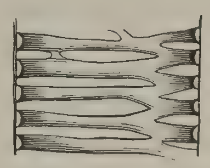


FIG. 98.

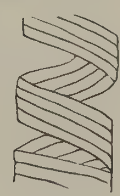


FIG. 99.

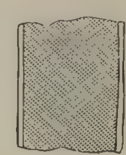


FIG. 100.

FIG. 90.—Cells of the pith of *Acanthus mollis*, seen in a vertical section, × 200 diam. (Henfrey).

FIG. 91.—Cells of a filament of *Spirogyra*, with spiral green bands, × 200 diam. (Henfrey).

FIG. 92.—Cells from the sporangium of *Marchantia polymorpha*, × 250 diam. (Henfrey).

FIG. 93.—Woody tissue or pleurenchyma, consisting of fusiform or spindle-shaped tubes overlapping each other. The walls of the tubes are thickened by deposits of lignine.

FIG. 94.—Spiral vessels, consisting of elongated cells which assume a tubular and fusiform shape, and have a spiral fibre formed on the inside of their walls (Balfour).

FIGS. 95, 96, and 97.—Spiral vessels from *Sambucus ebulus*, × 400 diam. (Henfrey).

FIG. 98.—Fragment of a vessel from the stem of a gourd, displaying circular bands, × 400 diam. (Henfrey).

FIG. 99.—Fragment of the wall of a reticulated vessel of rhubarb, × 400 diam

FIG. 100.—Fragment of the wall of a reticulated vessel of rhubarb, × 400 diam. (Henfrey).

Such being the nature and general course of the circulation in plants, we naturally turn our attention to the channels and forces by which the circulation is inaugurated and maintained.

In the cellular plants, such as the fungi and lichens, and even in the mosses and hepaticæ, there are no distinct channels for the transmission of fluids; the sap passing from cell to cell in a more or less complex series by a process of imbibition, much in the same way that water spreads in a piece of blotting-paper. In such cases the currents set most strongly towards those spots where growth is proceeding most rapidly, and where there is great functional activity. The same thing happens in the secreting and rapidly developing tissues of animals. Thus the blood is determined to the stag's horn when growing, to the mamma when suckling, and to the stomach when digesting.

§ 92. The Vessels of Plants: their Function.

In plants with well-defined stems and branches there are more or less perfect channels for the circulation of the nutrient material. Thus there are the so-called vascular tissues, formed by the fusion of perpendicular rows of variously-constituted cells. The walls of those cells are in many instances furnished with vertical, annular,

[1] In animals the currents are ascending and descending only when the creatures assume a vertical position. In animals whose bodies assume a horizontal position, the terms ascending and descending are obviously inapplicable. The great feature in the circulation to be kept constantly in view is that one current goes in one direction, and another in an opposite direction.

[2] "Recherches sur l'Endosmose et l'Exosmose." Paris, 1828.

spiral, reticulated, or other fibres; the cells by their union originating the spiral, annular, reticulated, scalariform, and other vessels. (*Vide* Figs. 90 to 100 inclusive; and Figs. 101 to 103.)[1]

Doubt has been expressed as to whether the vessels in question are actually engaged in the transmission of saps, but the preponderance of evidence is in favour of this belief. Mr. Herbert Spencer has been able to show, by recent experiments, that the passage of fluid through the spiral and other vessels is much more rapid than through the cellular tissue. By soaking young shoots which develop little wood in decoctions of logwood and other dyes, he discovered that the only channels stained by the process were those corresponding to the spiral, fenestrated, scalariform, and other vessels of the vascular system. Through these vessels consequently the coloured fluid must have passed. Nor is it wonderful that the fluid should have preferred open capillary channels, such as those formed by the vessels of the vascular system, to interrupted or non-continuous channels such as are supplied by cellular tissue, or any tissue not differentiated into continuous canals. Mr. Spencer took the precaution to immerse whole plants in his dyes, as well as parts of plants. He obtained the same result in both cases, so that it is natural to conclude the coloured fluids traversed the same channels traversed by the crude and other saps when submitted to the action of the plant. The spiral, annular, and other vessels of the vascular system are most engaged as sap-carriers when new wood is being formed in their vicinity, in which case also they are most porous.

When new wood is being formed the dye escapes from the vessels of the vascular bundles into the cellular and surrounding tissues in such quantity as to lead to the belief that the said tissues and not the vessels transmit the sap. This was the opinion of Hoffmann and Unger, who held that in plants possessed of fibro-vascular bundles, the sap in the first instance passes up from the roots chiefly in the parenchymatous cellular constituents of the bundles, and that these juices do not pass by the spiral vessels themselves. There are many circumstances which induce me to believe that the vessels and intervascular spaces are both engaged in the circulation.

Mr. Spencer's explanation of the passage of sap through the vascular tissues has been objected to on the ground that the spiral and other vessels of the vascular system frequently contain air. To this he replies, that they only do so during periods of drought, and when they are old—their function as sap-carriers having virtually ceased. The canals which ramify through the stag's horn, he observes, contain air after the horn is fully developed, but it is not thereby rendered doubtful whether it is the function of arteries to convey blood.[2]

It ought, moreover, not to be overlooked, that while the presence of air in the vessels is fatal to the circulation in animals, it does not of necessity follow that it is so in plants. The conditions are not identical. In animals the walls of the larger vessels are not permeable by fluids, so that air admitted into them has no means of escaping therefrom; in plants, on the contrary, the walls of the vessels are especially permeable, a free egress being provided by the pitted and other vessels.[3] The presence of air in the vascular bundles of plants is therefore a natural condition at certain periods—a plant requiring air as well as sap.

[1] The following footnote is collated from the works of Henfrey, Dutrochet, Herbert Spencer, Balfour, and the Author. It gives important information regarding the nature of cells and vessels, and the movements of certain parts of plants and animals:—

A number of cells permanently combined form the tissues of plants. If the cells entering into the composition of the tissue are essentially alike, they form a simple tissue. The simple tissues are divided into the cellular and vascular tissues. In the former (cellular tissues) the cells, however firmly coherent, are only *in contact* by their walls, which form a persistent boundary between them. In the latter (vascular tissues) the cells enter into closer relation, becoming confluent by the absorption of their contiguous surfaces, and thus converted into more or less extensive tubular bodies, which in their various conditions form what are called the *ducts* and *vessels* of plants. The vessels, it will be seen, are in reality compound elementary organs.

The presence of spiral fibres in cells is most instructive, for in this we see the foundation of a numerous class of structures which were otherwise inexplicable. A series of cells with spiral cell-walls originate a vessel with spiral walls; these vessels may twine in a certain direction and produce a spiral stem—the stem itself may twine around another tree in a spiral manner; leaves, flowers, fruit, branches and roots, may all be arranged in spirals of various orders. The spirals of plant structures may be traced in animal structures. The shell of the nautilus is rolled up in a most graceful spiral; the heart (ventricles of birds and mammals) is a double continuous spiral of exquisite beauty. The wings of birds and the extremities of bipeds and quadrupeds are distinctly spiral in their nature, and their movements are curved spiral movements; nay, more, the vertebral column itself is a spiral of very unusual but delightful curve. The soft cell fibres, equally with the bony skeleton, are twisted upon themselves morphologically. This is a point of great interest. It is important physiologically, as spiral continuous structures give rise to spiral continuous movements, as seen in walking, swimming, and flying, and in the movements of the hollow viscera.

Dutrochet ("Braun sur les Torsions normales dans les Plantes") states that there is a revolving movement in the summits of stems, a spiral rolling of the stems round their supports, a torsion of the stems upon themselves, and a spiral arrangement of leaves—all these being, in each plant, in the same direction. These phenomena, he avers, are owing to an internal vital force which causes a revolution round the central axis of the stem.

The annular thickenings are less common than the spiral ones, but sometimes occur in the same cell with reticulated ones.

The spiral vessels are found in the youngest and most delicate parts of plants.

In the young soft part of the shoot, as in all normal and abnormal growths that have not formed wood, the channels for the passage of sap are the spiral, annular, fenestrated, or reticulated vessels. The sap-carrying function is at first discharged entirely by the walls of the medullary sheath, and they cease to discharge this function only as fast as they are relatively incapacitated by their mechanical circumstances. It is not the wood itself, but the more or less continuous canals formed in it, which are the subsequent sap distributers.

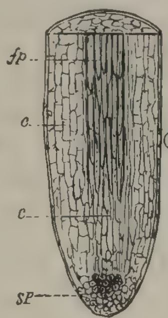
According to Mr. Spencer, there is no direct connection between the age of a vessel and its porosity; those vessels being always the most porous around which a formation of wood is taking place. Professor Balfour, on the other hand, states that the tubes forming the wood are pervious to fluids in their young state, but that their walls soon become thickened by deposits of lignine, and in the heart-wood of trees their cavities are obliterated. This filling up of the tube takes place often in a concentric manner, and when it is completed the active life of the cell or tube may be considered as having terminated.

[2] "Principles of Biology," vol. ii. p. 357.

[3] Globes of air in a capillary tube with rigid impervious walls require, as Janin has shown, a pressure of three atmospheres to force them on. As, however, the walls of the vessels of plants are porous, a much smaller force suffices; the air escaping in every direction.

§ 93. Points of Resemblance between the Vessels of Plants and Animals.

Making allowances for difference of opinion as to the function performed by the vessels of plants, there can be no doubt that the vascular tissues of the vegetable kingdom bear a close analogy to those of the animal kingdom. In the vessels of plants we have structures remarkably resembling those of the blood-vessels of animals. In an artery, as is well known, there are straight, annular, and spiral fibres, these being present in variable proportion, according to the thickness of the vessel and its distance from the heart. Thus in the aorta the longitudinal, spiral, and annular fibres are all present; whereas in the capillaries, fragments of the annular fibres alone appear. Very similar remarks may be made regarding the vessels of plants. In these the spiral vessels are found in the youngest and most delicate parts of the plant, the annular vessels being developed a little later in the same bundles, and in similar situations. The reticulated vessels are found in quantity with the spiral and annular kinds in succulent stems, roots, and petioles. The vessels of plants, like those of animals, are usually of a cylindrical form (Figs. 101, 102, and 103).



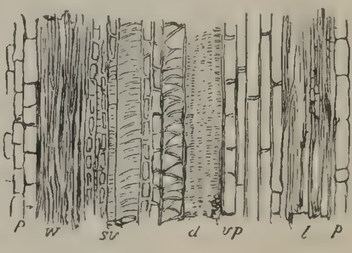


FIG. 101. FIG. 102. FIG. 103.

FIG. 101.—Vertical section of an orchis root, highly magnified. The cells, *c*, gradually pass into dotted cells and vessels, *fp*; the extremity of the root, formed of delicate cellular tissue, *sp* (after Balfour, p. 52).

FIG. 102.—Magnified representation of two plants of *Lemna minor*, or lesser duckwood—the green mantle of pools—showing the extremities of the roots covered by a cellular sheath (after Balfour).

FIG. 103.—Monocotyledonous fibro-vascular bundle (from the spadix of *Phœnix dactylifera*). Vertical section. *p*, Parenchyma, in which the bundles lie; *w*, wood cells; *sv*, spiral vessels; *d*, reticulated ducts; *vp*, *vasa propria*; *l*, liber cells. × 100 diam. (after Henfrey).

While the vessels of plants and animals may be said to be formed upon a common type, there is this great difference between them, and it is important as far as the circulation is concerned:—The vessels of plants, unless when quite young,[1] are rigid and have no independent movements; the vessels of animals, on the other hand, are flexible and elastic, and are in many cases endowed with independent motion. This is especially the case in the dorsal vessel of the insect, the veins of the bat's wing, the saphenous veins of the rabbit, the web and mesentery of the frog, the bulbus arteriosus of the fish, and the venæ cavæ and pulmonic veins of the mammal where they join the heart. There is this further difference, the principal vessels of animals, unless where *rete mirabile*[2] is present, are isolated, that is, they occur at intervals, with muscular, bony, and other tissues between. The vessels of plants, on the other hand, are in contiguity, and touch each other (Figs. 101 to 106).

FIG. 104. FIG. 105. FIG. 106.

FIG. 104.—Absorbent organ from the leaf of *Euphorbia neriifolia*. The cluster of fibrous cells forming one of the terminations of the vascular system is here embedded in a solid parenchyma (after Herbert Spencer).

FIG. 105.—A longitudinal section through the axis of an absorbent organ from the root of a turnip, showing its annuli of reticulated cells when cut through. The cellular tissue which fills the interior is supposed to be removed (after Herbert Spencer).

FIG. 106.—A less developed absorbent, showing its approximate connection with a duct. In their simplest forms these structures consist of only two fenestrated cells, with their ends bent round so as to meet. Such types occur in the central mass of the turnip (after Herbert Spencer).

The vessels of animals may be divided into three sets—the arteries, the veins, and the capillaries; and to these may be added a system of vessels lately discovered, the perivascular canals. The arteries conduct from the heart or centre to the periphery; the veins, from the periphery to the centre; the capillaries uniting the veins and arteries together. Outside, or between the capillaries, so to speak, are the perivascular canals. In like manner plants may be said to have three sets of vessels, an ascending and a descending set, which, as has been shown, radiate in the embryo from a central point. They have also what may fairly be regarded as a capillary system in their leaves, and also in their stems and branches (Figs. 104 to 106). Whether, therefore, we compare the actual structure, situation, or functions of the vessels in plants and animals, we shall find they have many things in common. The walls of the vessels in plants are flexible and elastic when young, those of

[1] The spiral vessels are found in the youngest and most delicate parts of the plant. As these vessels are formed originally by the confluence of cells which are elastic and flexible, a certain degree of movement may reasonably be claimed for them.

[2] In this remarkable arrangement, the blood-vessels sometimes run parallel to each other, and sometimes interweave in a most perplexing and unaccountable manner. The vessels are so numerous and so close, that they form one continuous mass. I have had opportunities of injecting them in the sloth, spider-monkey, and dolphin. They are found in various animals, their precise functions being at present undetermined.

animals being permanently so; the vessels of plants and the capillaries of animals are permeable by liquids and gases.[1] The veins of animals convey impure blood; corresponding vessels of plants, crude sap. The arteries of animals convey pure blood; corresponding vessels of plants, elaborated sap. The capillaries of animals expose the impure blood to the influence of the air; the capillaries in the leaves and other parts doing precisely the same thing for the plant. An animal may be said to breathe at every pore,[2] and so of the plant—a poisonous atmosphere being destructive to both. In animals it is necessary that the vessels extend to the part to be nourished, in order that the growing portions may absorb or imbibe from the blood what is required, while they return to it whatever is superfluous. In the brain and in bone, this absorption or imbibition takes place through considerable spaces. This is especially true of the so-called non-vascular tissues, as the cornea and lens of the eye, and the articular cartilages. The difference between the vascular and non-vascular tissues is only one of degree. In either case the structures lie outside the vessels, and obtain new material from the blood by imbibition. There is therefore an obvious analogy between the nutrition of plants and animals. In both cases the nutritious juices are presented to the growing tissues, immediately or remotely, by vessels or their representatives. In the capillaries of animals and the cells of plants, the limiting membrane is composed of an exceedingly delicate and apparently homogeneous substance, which greatly facilitates imbibition.

§ 94. Respiration in Plants and Animals.

By means of the capillaries of the lungs, and the capillaries of the body generally, the blood of animals is aërated, carbonic acid and other matters being given off and oxygen taken in. By means of the capillaries of the system, nutritious juices and white blood-corpuscles, also concerned in nutrition, are supplied to the tissues and effete matters taken up. By means of its vessels,[3] intervascular spaces, and leaves, a tree is nourished, grows, and breathes; it gives off oxygen and takes in carbonic acid and other matters.[4] It stores up starch and other compounds, and uses them as occasion demands. The tree, like the animal, may be said to breathe at every pore—by the stomata of its leaves, by its vessels,[5] intercellular passages and cavities of its stem and branches, and by its bark, when this is green. There is yet another point of resemblance between the respiration of plants and animals—the air given off by both is laden with moisture. The oxygen given off by trees and plants communicates to the atmosphere of the forest its peculiarly exhilarating qualities; the carbonic acid given off by the lungs of animals producing, on the contrary, a depressing effect.

§ 95. Cells of Plants, their Nature and Function.

As the cells of plants play a most important part in the general circulation, and have a circulation of their own, it is necessary to direct attention to them at this stage. "The cell is the elementary organ of a vegetable structure, but is not the smallest or most simple definite form in which organic matter may exist; it is not to be regarded as the ultimate structural unit, because detached fragments of it are capable of independent existence under certain circumstances," and a living plant may exist, at least for a time, in the absence of a bounding cell-membrane.

A vegetable cell may be defined as a closed sac, containing fluid or semi-fluid matter. It may represent an entire plant, or only part of a plant.[6] It contains, or may contain, protoplasm, a nucleus, a primordial utricle, starch and

[1] In the young cells of plants the cell-wall consists apparently of a homogeneous membrane which is elastic, flexible, and freely permeable by water. When the cells become older the cell-wall becomes firmer, and opposes a greater obstacle to the entrance of water into its substance. This leads me to conclude that the cell-wall is porous—a point difficult to determine, as the most powerful microscope fails to detect the pores. The molecular structure of cell-membranes has been investigated by Nägeli. From a careful examination of the cell-membrane of starch by polarised light, he came to the conclusion that *all organic substances are composed of crystalline molecules* grouped in a definite manner—that these molecules when dry have no interspaces, but that when moist each molecule is surrounded by a thin film of water. The epidermis of the young leaves of the leek, as Garreau has shown, is freely permeable by fluids; while the epidermis of the older leaves is either not permeable or very sparingly so. Garreau attributed a decided endosmotic property to the cuticle, which is greatest in young parts and least in old ones. When leaves are so old as to have lost the power of absorbing water they can still take up carbonic acid.

[2] Spallanzani was the first to point out that the tissues respired. The subject has likewise been investigated by G. Liebig. M. Paul Bert ("Leçons sur la Physiologie comparée de la Respiration": Paris, 1870) shows that the muscles of cold-blooded vertebrate animals consume, relatively to their weight, less oxygen and evolve less carbonic acid than the muscles of warm-blooded animals; also that the muscles of adult animals absorb much more oxygen and evolve more carbonic acid than those of young animals. He proves that all the tissues of the body absorb oxygen and give off carbonic acid.

[3] Some authors are of opinion that the spiral vessels and their allies are receptacles for gaseous matter formed in the course of the movement of the sap within.

[4] Leaves have the power of absorbing carbonic acid, ammonia, water, and aqueous solutions. They also inhale a certain amount of water, and they give off gaseous matters, especially oxygen. Thus leaves, in the performance of their functions, absorb and inhale water and gaseous substances. ("Class-Book of Botany," by J. H. Balfour, A.M., M.D., F.R.S., &c., 1871, p. 451.)

[5] In spring the vessels are found gorged with sap, but later on in the season *they usually contain air.* The intercellular passages are also filled with air. Professor Passerini, of Parma, has succeeded in showing that gases are exhaled through the stomata. He obtained his results by causing a plant to absorb a solution of sulphate of sodium, and then placing slips of paper saturated with acetate of lead to its leaves. The parts of the paper corresponding to the stomata were coloured dark, clearly showing that a reaction had taken place.

[6] The red snow plant and oscillatoria consist each of single isolated cells, the cell performing the function of nutrition and reproduction. The fungi and sea-weeds—the so-called cellular plants—are composed of numerous cells, arranged according to a definite order, some of the cells discharging the nutritive and others the reproductive functions. The higher or vascular plants have vessels added to the cells, the organs of nutrition and reproduction being more complicated.

chlorophyll corpuscles, and other substances. Here, then, is a mixture of heterogeneous material, each substance varying in density, and having its own peculiar properties and actions. The cell-wall is also of uncertain and varied constitution. It is regarded by some as originally consisting of a homogeneous membrane, in which spiral, annular, and other fibres are subsequently developed; others believing that these fibres are present in the cell from the first, and form an integral part of it. Agardh, for example, is of opinion that the cell-walls are made up of bundles of solid fibres interwoven together. He therefore attributes to the cell-wall a structure resembling that of the blood-vessels and hollow viscera of animals.[1] However this may be, the cell-wall in the young state, as already indicated, is elastic, flexible, and freely permeable by water; and this is important, as rendering the cell liable to all kinds of hygroscopic influences.

As the cell-wall becomes older it usually thickens and becomes more rigid; in which case water permeates it with more difficulty. We have therefore in any single cell, or in any combination of cells, the conditions necessary for a great variety of vital, mechanical, and chemical changes; the presence or absence of heat and moisture accelerating or retarding the changes in question. It may happen that the cell-wall (while thickening) remains soft and flexible, and, if so, it swells up the instant it comes in contact with water. If a unicellular plant be placed in a dense liquid, its contents escape, and it becomes shrivelled; if, on the other hand, it is put in a thin fluid, it imbibes the fluid and increases in volume. The red blood-globules do the same. These changes are principally due to endosmose and exosmose. The effect which changes of temperature have upon cells is very remarkable. The stomata of the leaves of plants close in dry weather and open in moist, so that the opening or closing of a part, while due in the first instance to the presence or absence of moisture, is due in the second to structural peculiarities in the cells themselves and to a variable temperature. Thus in some species of mesembryanthemum the seed-vessel is closed when dry, and open when moistened; whereas in the spores or germs of the horse-tail (*equisetum*), the cellular club-shaped filaments which form a part of it are widely expanded when the spore is dry, and closed when it is moistened. This would seem to imply the existence of two forces in plants,[2] portions of certain plants having the power not only of closing but also of opening. This appears to follow because the presence of moisture in the one case produces the closing, and in the other the opening. The same cause, if I may so phrase it, produces opposite results. A similar phenomenon is witnessed in the action of hollow muscles with sphincters, where, apparently under similar conditions, the sphincter opens or expands when the viscus closes, and *vice versâ*. I am inclined to infer from this that heat or dryness, and moisture or wet, do not act as irritants, and that plants and certain parts of animals move without being irritated. If moisture, for example, acted as an irritant, and caused one plant to close, it could scarcely be regarded as the cause of another opening. Moisture and dryness, moreover, act upon dead vegetable tissue, where the idea of irritability is inadmissible. Thus a hempen rope shortens when wetted, and elongates when dried. The manner in which cells of wood, liber, &c., swell up on the application of moisture, is deserving of attention. They expand in the direction transverse to their axes, that is, they shorten in a longitudinal direction as they bulge or swell out laterally.[3] Shortening in one direction is consequently elongation in another. Precisely the same thing takes place in the action of the sarcous elements of a muscle. When a muscle or an elementary muscular fibre contracts, as it is termed, it decreases in the direction of its length, and increases in the direction of its breadth—in fact the decrease in one direction is accompanied by an increase in another and opposite direction, the volume remaining always the same. It is therefore better, when speaking of the movements of long muscles, to say they shorten and lengthen, and of hollow muscles that they close and open, than that they *contract* and *relax*. The vegetable cell-wall, when dried, becomes smaller, so that the mere application or withdrawal of moisture suffices for conferring certain movements upon it.

These movements are to be regarded as extraneous, for the presence or absence of moisture may be an accidental circumstance. Cells, however, are living things, and they have living contents endowed in many cases with independent motion. The necessity for such an arrangement is obvious, inasmuch as "the vital and chemical phenomena exhibited by plants depend in the first instance upon operations which have their seat in the interior of those structures." Kühne proved the vitality of cell contents by a very remarkable experiment. He collected a quantity of protoplasm from a living plant, and placed it in a cockchafer's intestine. When he applied the stimulus of galvanism to the intestine so distended, it shortened like a muscle. The protoplasm possesses remarkable properties. In some plants it is endowed with distinct movements, rendered apparent by the granules which float in it. The source of these movements is at present a mystery; some authors contending that the protoplasmic

[1] In the cell-walls of *Polysiphonia complanata, Conferva melagonium*, and *Griffithsia equisetifolia*, Agardh has demonstrated numerous bundles of fibres, which cross each other at the joints to form the diaphragm. Between them finer fibres occur, the whole being united by a gelatinous substance. (Agardh, "De Cellula Vegetabili Fibrillis tenuissimis Contextu." Lundæ, 1852.)

[2] In the hygrometer, composed of *two pieces* of wood, each having different absorbing powers, a certain amount of moisture in the atmosphere produces a curving to the one side, a certain amount of dryness a curving to the opposite side.

[3] Henfrey's "Botany," p. 470.

mass can change its shape at any moment ; others, that the movements are due to increase or decrease in the amount of protoplasm contained within the cell at any given time.[1] Similar remarkable properties are to be attributed to the primordial utricle, which has the power of moulding itself into new external forms. The primordial utricle constitutes an envelope for the zoospore of the algæ, when it escapes from the parent cell ; the vitalised contents of the cell establishing a separate existence. The substance of the primordial utricle greatly resembles that of the amœba and the soft parts of sponges, all three being endowed with independent movements. The starch granules of cells are developed from the chlorophyll corpuscles, and these last owe their existence to the elaboration of protoplasm. There is thus a variety of movements going on within the cell during the period of growth.

§ 96. The Intra-cellular Circulation in Plants.

The intra-cellular circulation, or gyration, as it is called, is most interesting, and in some respects most mysterious. There can be little doubt that it is referable to vital, chemical, and physical changes occuring in the cell-contents ; but the precise nature of those changes is unfortunately at present not understood. Some investigators believe that the circulation is traceable to the nourishment of the cell, and the commotion consequent on its reproduction ; others to electrical or galvanic agency ; others to the presence of invisible cilia ;[2] and others to endosmose and exosmose, depending upon the different densities of the fluids presented from without to the cell-contents. It is therefore referred by one sect to vital, and by a second to physical action. Under these circumstances we can only refer to the phenomena as observed ; and it is not a little humiliating to think that at the very threshold of the circulation we are confronted with difficulties of such magnitude, and obliged to confess that even in a cell there are hidden powers which neither the microscope, physics, nor chemistry can as yet explain. From experiments which I have made recently, and which are fully described further on, it appears to me that the intra-cellular circulation is due in a principal measure to physical causes, such as absorption and evaporation, endosmose and exosmose, capillarity, chemical affinity, &c.

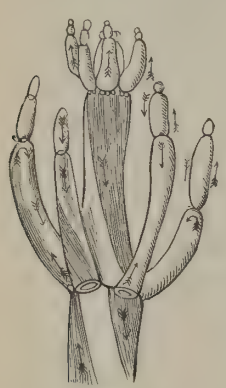


FIG. 107.

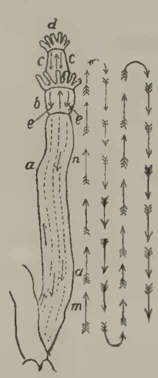


FIG. 108.

FIG. 109.

FIG. 110.

FIG. 107.—A small portion of a chara, magnified to show the intra-cellular circulation. The arrows mark the direction pursued by the fluid and granules in the different cells. The clear spaces are parts where there is no movement. The circulation in each cell is independent of that in the others (after Balfour).

FIG. 108.—Shows the course of the circulation in the stem of the polype (*Tubularia indivisa*). *a*, *a*, Horny tube containing a soft substance, continuous with stomach (*b*), and mouth (*c*) ; *c*, *d*, tentacula or arms. The ascending and descending currents in the stem of the polype are indicated by the darts. They pursue a slightly spiral direction, as indicated by the dotted lines in figure—the one setting towards the polype, the other away from it. At *m* and *n* there were vortices in the tube. The arrows to the right of the figure indicate the continuous nature of the currents within the tube (the Author, 1872).

FIG. 109.—Large internal cell of *Vallisneria*, showing the direction of the currents in intra-cellular rotation. There is an occasional nucleus seen in the course of the circulation, along with the chlorophyll grains (after Balfour).

FIG. 110.—Branching and anastomosing tubes of lactiferous vessels. In them there is an evident movement of granules of latex, as represented in some of the tubes in the figure, the arrows marking the direction of the current (after Balfour).

In many cells a distinct movement of fluids and granules is perceptible ; and Schleiden and Mohl are of opinion that these movements take place in all active formative cells at one period or other of their growth. The intra-cellular circulation is seen to advantage in many aquatic plants. It was discovered by Corti in chara in 1774.[3] In this plant (chara) the movements are of a spiral nature, as indicated by the arrows in Fig. 107.

It is not a little remarkable that in the stem of the *Tubularia indivisa*, a form of polype, precisely analogous movements occur, as was pointed out by Mr. Lister[4] (Fig. 108).

The movements in chara are made visible by the presence of granules, which rotate on their own axes, travelling in a spiral direction, up one side of the cell and down the other (Fig. 109). Observe, up one side of the cell and down

[1] During the time when the protoplasmic contents of young cells are becoming gradually hollowed out into spaces filled with watery cell-sap, a regular movement of this protoplasm takes place, which may be observed very readily in young hairs of phanerogamic plants, and which probably takes place in an early stage in all other structures. (Henfrey's "Botany," p. 551.)

[2] Movements analogous to the intra-cellular ones occur within the mouth, stomach, and rectum of certain polypes. Dr. Grant was of opinion that these movements were due to the lashing of cilia ; and Dr. Sharpey subsequently demonstrated that cilia actually did exist in the situations indicated.

[3] In chara the axis is composed of elongated cells, placed end to end, surrounded by a number of small secondary cells, which take a spiral course round the primary cells from left to right, and which are often encrusted with carbonate of lime.

[4] Movements somewhat resembling the above were found by Dr. Sharpey to occur in the tentacula of the actinia. ("Cyc. of Anat. and Phys.," art. "Cilia," p. 615.)

the other. The reversing currents referred to are seen to advantage in the lactiferous vessels of plants (Fig. 110). The currents in opposite directions, characteristic of the general circulation, reappear. The same currents are perceptible in our own stomachs during digestion. In the case of Alexis St. Martin, who had his stomach perforated by a gunshot wound, the food, when introduced into the stomach, was seen to circulate first along the greater curvature from left to right, and then along the lesser curvature from right to left.

It may seem far-fetched to trace an analogy between the gyrating of the contents of the human stomach and the gyrating of the contents of a vegetable cell; but, in some of the lower animals, the contents of the alimentary canal transude through its walls and circulate through the body; in others (polypes) the gyrating movements occur within the mouth, stomach, and rectum. I am, moreover, satisfied, from dissection and experiment, that the alimentary canal, stomach, and heart, even in ourselves, have many points in common; these organs being endowed with a pushing and pulling power, which enables them to propel their contents in given directions. When the œsophagus is engaged in transmitting food, it pinches on the bolus by opening before and closing behind it simultaneously—the expanding or pulling and pinching or pushing action accompanying the bolus from the time it enters the œsophagus proper until it reaches the stomach. This compound movement can transmit fluids with equal dexterity and precision, as is well seen when a horse or other large animal is drinking; an acrobat, as is well known, can drink when standing on his head. Every part of the œsophagus has the power of opening and closing, so that the part which is opened the one instant is closed the next, and *vice versâ*. The opening and closing movements which constitute the œsophageal rhythm travel, in normal swallowing, in the direction of the stomach; but the direction of the movement, in abnormal swallowing or vomiting, is reversed; showing how perfectly the opening and closing power is possessed by the œsophagus. Those animals which ruminate, swallow in both directions: first, from the mouth towards the stomach; second, from the stomach towards the mouth; and third and finally, from the mouth back again to the stomach. This power is possessed by man himself, some individuals being able to vomit at pleasure, and others confirming the habit to such an extent as to be actually able to ruminate. The power possessed by the alimentary canal of opening at one part, and closing at another, is well seen in invagination; the closing portion of gut forcing itself into or within the opening portion—the act of expansion assisting the movement in virtue of the opening and closing portions travelling in opposite directions. The act of invagination is produced by a double movement, similar to what would be produced in the œsophagus of a ruminating animal if the swallowing and ruminating movements occurred at the same time. This power which the intestine occasionally exerts of shortening its length by invagination is, I apprehend, a power possessed, within certain limits, by all muscles—the sarcous elements of a muscle when the muscle shortens tending towards a central point, from which they recede when the muscle elongates, very much in the same way as Professor (now Lord) Lister has shown the pigment-cells in the frog's skin converge towards a point at one time and diverge at another. When the sarcous elements of a muscle converge in one direction—say in the direction of the length of the muscle—they diverge in the opposite direction, namely, in the direction of the breadth of the muscle; so that, in reality, it is a misnomer to apply the term contraction to a muscle when it shortens—the act of shortening in one direction being actual lengthening in an opposite direction. This follows, because the sarcous elements of a muscle, or the muscle as a whole, when it moves or acts, simply changes shape; the volume of the muscle and the sarcous elements composing it always remaining exactly the same.

I have already referred to this subject when speaking of the structure and action of the blood-vessels and heart of animals, and will again take it up further on; meanwhile I would direct attention to the fact that the stomach may be regarded as simply an expanded and elaborated portion of the alimentary canal, and the heart as an expanded and elaborated portion of the vascular system; the stomach and heart being constructed on precisely the same type, and performing analogous functions as far as their movements are concerned. Further, the structure and functions of the bladder and uterus closely resemble those of the stomach and heart; so that the hollow muscles and blood-vessels may be placed in the same category. They all receive fluid, semi-fluid, or solid substances, which they contain and expel at regular intervals. The stomach can cause its contents to gyrate like those of a vegetable cell, and the œsophagus, by the rhythmic movement of its several parts—that is, by the simultaneous opening or widening of one part, and the closing or narrowing of another part (say the part behind that which opens)—can seize and dismiss the food, and pass it on in successive waves to the stomach; just as a blood-vessel with rhythmic movements, or the heart itself, can pass on the blood in successive waves, in a given direction. If, however, one part of the œsophagus closes or narrows while the part beyond expands or widens, the œsophagus in this way foreshadows the movements which occur in the stomach, where the pyloric sphincter opens when the stomach closes, and *vice versâ*. I use the terms "opens" and "closes," in preference to "relaxes" and "contracts," because I regard the opening of the sphincter and the closing of the stomach as equally vital acts. This view is borne out by the structure as well as the action of the parts. In man the stomach has two sphincters, a cardiac and a

pyloric one. Each of these is composed of two sets of looped symmetrical fibres. The sphincters resemble the valvulæ conniventes, and I am disposed to regard them as simply differentiated valvulæ conniventes, from finding the two halves of the pyloric sphincter of the dog slightly separated from each other—valvulæ conniventes, or what is equivalent thereto, being indicated in the œsophagus of the cat. If, therefore, the stomach be regarded as an expansion of the intestine, and the sphincters as constrictions or partitions which are structurally identical with the other parts of the stomach; and if, further, the œsophagus and intestines have peristaltic movements, that is, the power of simultaneously narrowing and widening in parts, then we are bound to conclude that the closing of the stomach and the opening of its sphincters are equally vital acts. But for this co-ordination the movements would be purposeless. The structure of the intestine remarkably resembles that of many vessels where we have non-striated longitudinal and circular fibres. But many blood-vessels have distinctly rhythmic movements, so that structurally and functionally the intestines and blood-vessels resemble each other.

The movements in chara, as has been stated, are made visible by the presence of granules, which rotate on their own axis, travelling in a spiral direction up one side of the cell and down the other. The granules vary in size, and are elaborated *in transitu* to fit them ultimately for becoming part of the cell-wall. They may therefore be likened to the white blood-corpuscles of animals, which, as recent researches have shown, are also incorporated directly into the tissues. In vallisneria similar intra-cellular movements occur. "Spiral movements of rotation are also seen in the elongated cells forming the hairs of the nettle, loasa, pentstemon, galeopsis, borage, melon, and other plants; as well as in the separate cells of the staminal hairs of the Virginian spiderwort (*Tradescantia virginica*)." [1]

The rotations of the protoplasmic contents of cells exhibit a marked resemblance to those of the protozoa; and many observers are of opinion that the moving bodies owe their power of rotation in part to ciliary processes similar to those which render many of the simpler plants locomotive. This view is entitled to favourable consideration, the more especially as ciliary motion has been discovered by Dr. Sharpey and others in the embryos of infusoria and gasteropoda, while inclosed in the ovum; [2] and in the ova of the polype, sponge, mollusc, and actinia. Similar gyrating movements have been observed within the stomach of the polype.[3] In all these cases the presence of cilia has been distinctly made out. If cilia could be proved to exist on the lining membrane of the cell-wall of plants, or on the exterior of the moving particles, much of the mystery of gyration would disappear. Until, however, these are discovered we must fall back upon other forces, and of these I believe *absorption* and endosmose on the one hand, and *evaporation* and exosmose on the other, to be the chief.[4]

A moderate heat quickens the intra-cellular circulation, which is arrested if the temperature be elevated above 150°. It is also arrested by prussic acid and alcohol, as well as by solutions of acetate of lead, opium, and corrosive sublimate. Prussic acid, alcohol, and the solutions in question, may destroy the intra-cellular circulation by poisoning and paralysing the tissues, and by inducing an imperfect osmose; for Dutrochet found that all acids, alkalis, soluble salts, alcohol, &c., because of their susceptibility to enter into combination with the permeable partition of the endosmometer, destroy endosmosis, although they had induced it before their complete combination with the elements of the membrane had taken place; and it is not until this combination is complete that endosmosis ceases. I regard the intra-cellular circulation in plants, and the circulation in plants generally, as so important that in 1872 [5] I instituted an elaborate series of experiments to show how they may all be successfully reproduced. These experiments I repeat here with their original illustrations. The intra-cellular movements are in a great measure due to osmose, evaporation, and capillarity. Thus, if capillary syphon tubes be arranged to act upon opposite points of a glass cell, and supplied with water, they cause the fluid contents of the cell to gyrate (Fig. 113). Again, if a glass cell be filled with syrup, and endosmotic currents induced on opposite sides of the cell above and below, the syrup begins gradually to rotate (Fig. 111). The same happens when the syrup is allowed to evaporate from opposite points (Fig. 112).

Endosmosis and evaporation may produce gyration by a conjoined action. When endosmosis and evaporation act separately the gyration is in opposite directions (compare arrows of Figs. 111 and 112). While gyration may be induced mechanically by the operation of physical forces, the life of the plant exercises an influence in its production.

As a proof that the presence or absence of moisture will not account for all the phenomena witnessed in cells, it may be stated that in the sensitive plant (*Mimosa pudica*) there is a swelling at the base of the petiole, the cells

[1] "Class-Book of Botany," by J. H. Balfour, A.M., M.D., F.R.S., &c., p. 417.
[2] Abhandl. der Akad. der Wiss. zu Berlin für 1831.
[3] "Cyc. of Anat. and Phys.," article "Cilia," by Dr. Sharpey, p. 610.
[4] Rusconi found that when the embryo of the frog was extracted from the ovum it revolved. He attributed this movement to water entering and issuing from the pores of the skin. ("Sur le Développement de la Grenouille Commune." Milan, 1826.)
[5] "The Physiology of the Circulation in Plants, in the Lower Animals, and in Man." (*Edinburgh Medical Journal*, 1872–73.)

of which constitute, as it were, two springs which act in opposite directions; so that if from any cause the one be paralysed, the other pushes the leaf in the direction of least resistance. This is exactly what happens in hemiplegia, the tongue when protruded being forced by the healthy muscles towards the paralysed side; muscles, as has been already indicated, having a power of elongating as well as of shortening. If, as is universally believed at present, muscles have only the power of shortening, the tongue would be drawn towards the healthy side, which it is not.[1] The springs, if they may so be called, situated at the base of the petiole, are set in motion by the rush of fluid, creating a turgid state of the one set of cells, and an empty state of the other. A kind of rhythmic movement is thus produced. What is it, one naturally inquires, which gorges the one set of cells and empties the other, if it be not a vital power exercised by the plant? The fluid, be it noted, is at the disposal of both sets of cells. The same fluid certainly cannot stimulate the one set of cells to shorten and the other to lengthen; and besides, so far as is known, there are no contractile tissues present in the plant. Neither can the presence of moisture act as an irritant, moisture being necessary to the life of the plant, and a normal part of it. The only explanation that can be given is, that the plant lives, and that it sucks in moisture by the one set of cells, and ejects moisture by the other set, just as one part of the heart sucks in blood while another expels it. The blood is not the stimulus to this act. In the same way the stomach, bladder, rectum, and uterus close or shorten in one part and open or lengthen in another when the proper time arrives for expelling their contents. Here, again, the contained matters are not to be regarded as irritants, in the ordinary acceptation of the term. If they were, they would be expelled long before they were collected in normal quantity.

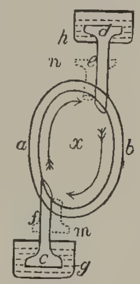


Fig. 111.

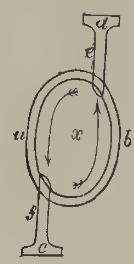


Fig. 112.

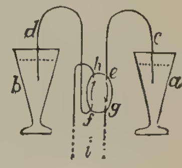


Fig. 113.

Figs. 111 and 112.—Show how the gyration of the cell contents may be produced either by absorption, by endosmose, or by evaporation, or by all the three. Fig. 111, *a*, *b*, cell containing viscous fluid; *c*, *d*, absorbing surfaces of cell surrounded by water or other thin fluid (*g*, *h*); *x*, endosmotic currents, which result in gyration (*vide* arrows), are thus produced. To the absorbing surfaces, evaporating ones, as at *e*, *n*, *f*, *m*, may be added. Fig. 112 shows how gyration may be effected by evaporation alone. *a*, *b*, Cell containing viscous fluid; *c*, *f*, *d*, *e*, evaporating surfaces. The arrows (*x*) indicate the direction in which the evaporation acts (the Author, 1872).

Fig. 113.—Shows how fluids washing the opposite sides of a cell in opposite directions will cause the cell contents to gyrate. *c*, *d*, Capillary syphon tubes, the extremities of which communicate with water in the vessels *a*, *b*, and with a viscid fluid in the cell *h*, *e*, *f*, *g*; the one syphon enters the cell at *e*, the other at *f*; capillary tubes being inserted at *g* and *h* to carry off the superfluous fluid (*i*). The fluid within the cell gyrates, as indicated by the arrows. This is ascertained by introducing powdered charcoal into the fluid contained within the cell. In the present diagram the cell has been placed on a lower level than the water contained in the glasses; but it might have been placed as high above the water as it is below it, the gyration within the cell not being produced by the gravitation of the water in the vessels acting through the syphon tubes, but by capillarity alone (the Author, 1872).

Movements greatly resembling those of the petiole of the sensitive plant occur in the cilia of the polygastric infusoria. Ehrenberg showed that each of the cilia in question has a bulb at its root, to which minute muscles are attached. Those muscles shorten and lengthen alternately, and so the cilia are lashed about with a flail-like motion. If the body of one of those curious creatures is fixed, the cilia excite currents in the water in which it is immersed; if the body be free, they serve as organs of locomotion. In this case there can of course be no doubt as to the vitality of the movements, and the entire absence of anything in the shape of irritation.

It is most interesting to find in an aggregation of plant-cells movements so obviously analogous to those of muscles. When the one set of cells, Henfrey[2] informs us, is contracted, the other is expanded, and *vice versâ*. According to Mohl, "The expansion of the cellular tissue on the upper side of the articulation of a leaf counteracts a similar expansion of the cellular tissue on the under side; but if the upper cellular tissue be removed, so that the under cellular tissue is deprived of its antagonist, the equilibrium is destroyed, and *the leaf is pushed upwards*. The reverse of this happens when the under cellular tissue is removed."[3] Here again we have an illustration of what happens in hemiplegia when the tongue is protruded. The tongue is *pushed towards the paralysed side*, and if the paralysed half of the organ were removed, the result would be precisely the same as in the plant. The leaf, it will be observed, is kept in a state of equilibrium by the presence of two forces equally balanced, and the same may be said of the tongue. The leaf and the tongue are free to vibrate on any slight disturbance of the equilibrium. When the leaf is no longer required for the growth of the plant, it is amputated by a vital process, and not by any vicissitude of climate; in fact, the process of disjunction begins with the formation of the leaf-stalk, and is completed when the leaf ceases to be useful. Other vital actions might be cited in this connection which go to prove

[1] Sir Thomas Watson, in speaking of hemiplegia, says, "When the tongue is put out beyond the lips, its point is commonly turned to one side. To which side? Why, *towards* the palsied side. For what reason? Clearly because the muscles that protrude the tongue are powerless on that side, and in full vigour on the other. That half of the tongue which corresponds with the sound side *is pushed further out* than the other half, and therefore the tongue bends to the palsied side. Such is the usual fact, and such the explanation of it." ("Principles and Practice of Physic," 4th ed. vol. i. p. 503.)

[2] Henfrey's "Botany," p. 628.

[3] "Anatomy and Physiology of the Vegetable Cell."

that plants, within limits, control their own functions—even the roots having a selective power. The remarks made regarding the movements of the hollow muscles and tongue apply equally to the flexors and extensors of the voluntary muscular system; but, as I shall have occasion to return to this subject, I will merely observe, in passing, that it is not a little remarkable that a mere congeries of cells devoid of nerves and contractile tissue should have the power, so to speak, of acting rhythmically, and of producing motions in definite directions in the absence of an exciting cause—at all events, in the absence of anything which partakes of the nature of irritation. With these facts before our eyes, it is not difficult to understand that voluntary and involuntary muscles have a centripetal and centrifugal action; and by this I mean a power by which long muscles shorten and lengthen, and hollow muscles close and open.

The intra-cellular circulation of plants, as a rule, pursues a definite direction. The moving particles, however, occasionally stop, reverse their course, and commence *de novo*. This circumstance inclines me to believe that absorption, evaporation, and osmosis play an important part in the gyration of cell contents. That the vitality of the plant is also concerned in the production of the intra-cellular circulation is rendered all but certain by its occurring only in the active living cells which are engaged in building up the plant, and by its ceasing if the part of the plant in which it occurs is injured.

That cells are endowed with vitality, and that this of itself is capable of setting inert matter in motion, is proved by the fact that some of them in the lower tribes of plants move about in a liquid medium; the oscillatoria advancing with an undulating motion. The ova of polypi and sponges also move freely about before they become fixed. This is necessary to spread the individuals of the original community. To this end they are provided with numerous minute cilia on their exteriors, which serve the purposes of locomotion and respiration. Similar moving cells are seen in stephanosphæræ and other genera of volvocineæ; and the cellular spores of many algæ are surrounded by cilia or vibratile hairs which, in fluids, move for some time after the spore (zoospore) has been discharged from the plant.

If we accord the power of motion to an entire cell, we shall have difficulty in resisting the conclusion that it also regulates the movements occurring within itself.[1] Further, in some of the lower plants, as has been stated, the living cell contents actually emerge from their temporary prison in the shape of zoospores, which lead an itinerant life until they find a suitable habitat.

The primordial utricle has, moreover, the power of assuming new shapes; this remarkable structure, when the cell is dividing, constricting itself, in two or more places, *without wrinkling*. But I need not pursue the inquiry further; suffice it to say, that the vital, physical, and chemical phenomena witnessed in plants are due primarily to operations occurring in the interior of cells; the functions of nutrition, reproduction, &c., necessitating movements in certain directions. In connection with the belief that the process of nutrition results in movements of a more or less definite character, I would here cite the name of one revered in physiology and pathology—namely, Sir James Paget—who gave it as his opinion that the contraction and dilatation of the heart itself are due to the nutrition and growth of the organ. He says, "But there is another thing common to all rhythmically acting organs, —they are all the seats of nutritive processes; and I believe that their movements are rhythmical, because their nutrition is so; and rhythmic nutrition is, I believe, only a peculiar instance or method of manifestation of a general law of time as concerned in all organic processes. In other words, I believe that rhythmic motion is an issue of rhythmic nutrition, that is, of a method of nutrition in which the acting parts are, at certain periods, raised with time-regulated progress to a state of instability of composition, from which they then decline, and in their decline may change their shape and move with a definite velocity, or (as nervous centres) may discharge nerve force." [2]

Certain plants, when vigorous and exposed to a bright light, exhibit rhythmical movements, and notably the Hedysarum (*Desmodium gyrans*), a native of the East Indies. The leaf in this plant is unequally pinnate, consisting of a larger leaflet at the end of the stalk, and two pairs of leaflets placed laterally. The smaller leaflets come towards and recede from each other with a jerking motion, every three minutes or so. The movements of the heart are certainly not more singular than those of the leaves now referred to. It cannot be the light or heat which produces the movements of the leaflets, for they go on in the dark; and as they are most regular when the plant is most healthy, we are not entitled to assume the presence of stimuli in the shape of extraneous irritation. The movements of the leaflets foreshadow a heart, and teach us one very important fact, namely, that living organs can come and go, contract,[3] expand, and perform stated motions at stated intervals, without the presence of nerves, muscles, elastic and other tissues; unless perchance these exist in an undifferentiated form, which is by no means improbable.

[1] Some authors attribute the contraction occurring in cells to alternate turgescence and emptying of certain portions of the protoplasm; but, as has been explained when speaking of the movements of the petiole of the sensitive plant, turgescence, and the absence of it, may be equally traced to vital influence.

[2] Croonian Lecture, "On the Cause of the Rhythmic Motion of the Heart," by Sir James Paget, Bart. *Proc. Roy. Soc.*, May 28, 1857.

[3] In the wild lettuce (*Lactuca virosa*), and in the stings of nettles, the cells, on being touched, contract and exude their fluid contents. The

According to Fee, the fluids drawn to the surface of a plant during light are kept in equilibrium by rhythmical evaporation ; the rhythmical movements of the leaves being referable to vital changes in the cell contents and vessels.

Sir James Paget adds, " Probably the simplest example of rhythmic motions yet known is that detected by the acute researches of Professor Busk in the *Volvox globator*.[1] At a certain period of the development of this simplest vegetable organism there appear in each zoospore, or in the bands of protoplasm with which the zoospores are connected, vacuoles, spaces, or cavities, of about $\frac{1}{1000}$ of an inch in diameter, which contract with regular rhythm, at intervals of from 38 to 41 seconds, quickly contracting and then more slowly dilating again." Now, however it may be with the heart, there is no room for doubting that the closing and opening of the vacuoles, spaces, or cavities here spoken of, are equally vital acts. They close quickly and open slowly, just as in the heart ; and my impression is that the different parts of the heart close and open alternately and independently ; the closing of the auricles taking no part in the opening of the ventricles, and *vice versâ*. In other words, the auricles close and open by spontaneous vital efforts, as do likewise the ventricles ; the movements of the auricles and ventricles being simply co-ordinated for a purpose. Indeed the structure and arrangement of the muscular fibres of the heart forbid any other assumption. If we take the muscular fibres of the ventricles, we find they are arranged in spiral figure-of-8 loops, the fibres being continuous upon each other, and crossing, at various degrees of obliquity, with mathematical precision ; some being vertical, some slightly oblique, some very oblique, and others transverse or circular. When the fibres spontaneously shorten they likewise thicken ; this shortening and thickening obliterating the ventricular cavities from above downwards in a vertical direction, and from without inwards. When the ventricles are closed, all their contained blood is ejected. As the blood, forced on by the closing of the auricles, cannot obtain admission to the firmly-contracted ventricles, this fluid cannot mechanically distend the ventricles. The ventricles are therefore under the necessity of spontaneously opening just as they spontaneously closed. During the closing movement or systole there is a shortening and thickening of all the muscular fibres of the ventricles ; during the diastole or opening movement, there is a lengthening and thinning of the muscular fibres. When the muscular fibres of the ventricles shorten and thicken, those of the auricles lengthen and become thinner, and *vice versâ ;* and this is precisely what happens in hollow muscles with sphincters. But for the double power which muscles possess of shortening and lengthening, it would be impossible to explain how the pyloric valve of the stomach is firmly closed during the first stage of digestion, how it partly opens to allow the chyme to pass during the second stage, and how it opens wide to admit of the passage of the more indigestible portions of the food during the third stage. He proceeds : " The observations of Cohn,[2] published about a year later than those of Mr. Busk, but independent of them, discovered similar phenomena in *Gonium pectorale* and in *Chlamydomonas*, the vacuoles, like water-vesicles, contracting regularly at intervals of 40 to 45 seconds. The contractions and the dilatations occupy equal periods, as do those of our own heart ventricles ; and in *Gonium* he has found this singular fact, that when, as commonly happens, two vacuoles exist in one cell, their rhythms are alike and exactly alternate, each contracting once in about 40 seconds, and the contraction of each occurring at exactly mid-distance between two successive contractions of the other. Here, then, we have examples of perfect and even compound rhythmic contractions in vegetable organisms, in which we can have no suspicion of muscular structure, or nervous, or of stimulus (in any reasonable sense of the term), or, in short, of any of those things which we are prone to regard as the mainsprings of rhythmic action in the heart." [3]

§ 96 (*a*). The Lactiferous Circulation in Plants.

Scarcely less interesting and curious than the intra-cellular circulation, is that occurring within the lactiferous vessels. The lactiferous vessels of plants have been likened by Carpenter to the capillary vessels of animals ; but they may, I think, with greater propriety be compared to the lacteals and lymphatics. The lactiferous vessels differ from the other vessels of plants by their branching and freely anastomosing with each other. Some authors regard them as cellular canals which are lined with a special membrane. However this may be, they are generally believed to contain the elaborated sap, which has been exposed to the influence of light and air. The movements occurring within the lactiferous vessels are seen to most advantage in plants with milky or coloured juice, as the india-rubber plant, gutta-percha tree, lettuce, and dandelion.

To the lactiferous movements the name of cyclosis has been given ; and Schultz was of opinion that they are vital in their nature. They are in some cases so rapid as to resemble the circulation in the web of the frog's foot. They take place in all directions, the currents being usually most vigorous where the plant is developing most rapidly.

small leaflets of the sensitive mimosas display cellular swellings at the roots, which, when touched, communicate motion to the leaves. Those swellings apparently consist of two kinds of cells, the one kind having the power of contracting, the other of dilating. (Dutrochet, "Sur la Structure Intime des Animaux et Végétaux," 1824.)

[1] *Transactions of the Microscopical Society of London*, May 21, 1852.

[2] "Untersuchungen über die Entwickelungsgeschichte der Mikroskopischen Algen und Pilze." Breslau, 4to, 1854.

[3] Croonian Lecture, "On the Cause of the Rhythmic Motion of the Heart,' by Sir James Paget, Bart., F.R.S. *Proc. Roy. Soc.*, May 28, 1857.

They are quickened and retarded by heat, electricity, and various physical forces to which allusion will be made presently. It is next to impossible to give a wholly satisfactory explanation of the lactiferous circulation and allied phenomena in the present state of science. The difficulty is increased by the fact that the vessels in which they occur, so far as is known, are *non-contractile.* I am disposed to believe that the lactiferous vessels form a complicated series of interlacing syphon tubes (see Fig. 110); the milky and other juices oscillating in them in obedience to atmospheric and hygrometric and physical influences—the oscillations being regulated within limits by vital laws and affinities. I refer at length to this view further on.

§ 97. The Forces which Produce the Circulation in Plants.

In the winter a tree may be said to be in a dormant condition. With the early spring comes fresh life, for then the stem and branches swell and the shoots and young leaves come forth. The warmth of spring inaugurates the circulation; but evaporation cannot as yet be said to take any very active part in it. The cell tissues of the tree, contracted and dry in winter, are in the best possible condition for receiving sap in the spring. This the roots supply in quantity. Through the roots and through the stem and branches a steady upward stream flows in direct opposition to gravity, and in the absence of any propelling force. This is a phenomenon which can only be explained by a *vis a fronte* traceable to nutrition and other changes going on in the cells, and to osmotic [1] and capillary action.[2]

In the ferns, according to Hoffmann, there are no channels for the descent of fluid, the sap simply ascending and diffusing itself in the substance of the plant in its progress. These plants grow by additions to their summits (acrogens), and this fact has much to do with determining the upward current, the leaf-action being virtually one of attraction or suction. It ought to be stated, that inasmuch as the upward current is mainly due to endosmose, a certain proportion of downward current, as has been already explained, is under the circumstances unavoidable. This is necessary for the growth of the stem.

That nutrition has much to do with the circulation in plants and the circulation generally, is proved by the fact that the current always sets most strongly towards those points where growth is proceeding most rapidly: a vine, for example, which is being forced by artificial heat, drawing the sap with immense force, although its root is placed outside the forcing-house and not participating in the heat. That osmose plays an important part is certain, from the fact that the juice presented to the cells by the roots is less dense than that contained in the cells; the free interchange of fluids of different density through the cell-wall and vascular tissues which are freely permeable being unavoidable. The direction and varying rapidity of the endosmotic and exosmotic currents are exactly suited to the requirements of the circulation. The rapid upward rush of the thin crude sap, and the slow percolation downwards of the dense elaborated sap, are just what *à priori* we should expect. The fluid to be elaborated must pass up to the leaves, to be transformed into the *succus proprius* or true food of the tree, and the more rapidly it does so the better. It is otherwise with the elaborated fluid. This is to be carefully distributed to every part of the plant, nourishing the plant and storing up future nourishment as it goes. A rapid downward movement would be unsuitable for the object to be attained. That capillarity contributes its quota is rendered apparent by the fact that the vascular bundles and interspaces are capillary in their nature, and water will travel through them when detached from the tree. The four great factors in the circulation, namely, nutrition, osmosis, capillarity, and evaporation, are intimately associated and may be considered together. The spongioles of the root imbibe watery sap or moisture, and present it to the cells of the root,[3] which present it to the cells and vessels of the stem; these in turn presenting it to the branches, shoots, leaves, and other growing parts (Fig. 101). In this they exercise a selective power, for Saussure has shown that if the roots of plants be immersed in a liquid containing equal quantities of different salts, they invariably take up more of the one salt than the other; some plants preferring one salt some another. This only happens when the roots are entire. When the roots are cut the two salts are taken up in equal proportions.

[1] Dutrochet is of opinion "that endosmose is due to a state of commixtion within the capillary tubes of the septum, and that the two opposed fluids proceed the one towards the other, with cross but unequal motions." "M. Poisson and William Power have each in his own way given an analytical explanation of the phenomenon of endosmose, and ascribed it to the action of the capillary canals of the porous septum interposed between the two fluids. In this explanation the phenomenon of the current of exosmosis is set aside, or regarded as occurring merely accidentally. Now this is entirely opposed to the fact; we have constantly evidence of the simultaneous existence *of the two opposite and unequal currents of endosmosis and exosmosis.*" ("Cyc. of Anat. and Phys.," article "Endosmosis," by Dutrochet, vol. ii. pp. 101, 102.)

[2] The height to which different fluids rise in capillary tubes depends on a variety of causes, in appearance very different, but which must have some fundamental analogy. Of all fluids, water is that which rises highest; and substances held dissolved in it which increase its density lessen its power of capillary ascent, which is also diminished by increase of temperature; hot water ascends a less way in a capillary tube than cold water. Combustile fluids, such as alcohol and ether, are like dense fluids in regard to power of capillary ascent, so that combustibility acts in the same manner as density in this respect. The matter of which capillary tubes are formed is also endowed with the power of modifying the capillary ascent of fluids. Thus water at the same temperature will not rise to the same height in a series of equal capillary tubes made of different material. (Ibid., vol. ii. p. 103.)

[3] "Recherches Chimiques sur la Végétation," pp. 247, 261.

Goodsir—philosopher, anatomist, and physiologist in one—drew a parallel between the spongioles of the roots and the external layer of cells situated on the club-shaped extremities of the villi of the placenta. He says, these cells are to the ovum what the spongioles are to plants; they supply it with nourishment from the soil in which it is planted. Thus their action is selective; and they transmit into the interior of the villus the materials necessary for fœtal growth. The nutritive plasma is then taken up by the internal layers of cells, and by them brought into direct contact with the fœtal capillaries. Here a beautiful analogy is established between plants and animals. The processes of nutrition and growth are essentially the same in both cases. The cells of the placental villi and the spongioles of the plant, as stated, each exercise a selective power; they absorb what is beneficial, and reject what is prejudicial. They are endowed with a double function; they can take in or assimilate new nutritious matter, and give off or reject non-nutritious or effete matter. In the plant a thin liquid is drawn from the earth by the spongioles and rootlets, and presented to a thicker liquid of variable constitution found in the cells and vascular tissues. What happens is this :—The walls of the cells and vascular canals being freely permeable, the thin fluids rise rapidly into the thicker fluids, the latter falling slowly through the thinner ones. Here, then, we have what virtually amounts to a vigorous upward circulation, and a feeble downward one. Precisely the same thing happens in an osmometer (Fig. 88). If, for example, a dense liquid is confined in a bladder, and the bladder be immersed in a thinner fluid, the thinner fluid rises rapidly through the thicker one—the thicker fluid descending slowly into the thinner one. The dense fluid is briskly penetrated by the thinner fluid either from above or from below, according to the position of the latter—gravity having no power in the matter. By adding exosmosis as one of the forces of the circulation to endosmosis, we are able to explain the reverse currents which we know exist in the circulation of plants; we are also able to explain how the two currents vary in rapidity—how they are more vigorous at certain periods of the year—how they are interrupted and seem to oscillate at times—and how they nearly or altogether cease in winter. In endosmosis and exosmosis we have two forces which bear a fixed relation to each other.[1] Both operate at the same time. If the one is interrupted, so is the other. It is in virtue of this arrangement that the movements of the sap can be quickened in spring, slowed in autumn, and discontinued or stopped in winter. Moisture, heat, and a living plant supply the conditions. If a part of a plant be forced (the other parts of the plant and roots being outside the forcing-house) endosmosis and exosmosis are at once called into operation in the part forced—the saps ascending, descending, and transfusing themselves laterally. If the forcing is suddenly discontinued, the circulation is arrested and growth checked. The same thing happens when frost chills a plant in early spring. It is thus that the plant and the circulation in the plant respond to outward influences: the circulation varying at different periods of the year, and of the day and night.

It is difficult to understand how excess of moisture in the ground can be drawn up into the plant and exhaled by the leaves at one period, and excess of moisture in the atmosphere seized by the plant and discharged by the roots at another. The explanation, however, is obvious, if we call to our aid the forces of endosmosis and exosmosis. The tree is always full of tenacious dense saps, and it is a matter of indifference whether a thinner watery fluid be presented to its roots or its leaves. If the thinner fluid be presented to its roots, then the endosmotic or principal current sets rapidly in *an upward direction;* if, on the other hand, the thinner fluid be presented to its leaves, the endosmotic or principal current sets rapidly in *a downward direction.* That two fluids of varying density, such as those situated without and within a plant, will pass through each other in opposite directions, whatever their position, may be proved by experiment. If, for example, I take two tubes, one end of each of which is covered by an animal membrane, and place water in the one and syrup in the other, I find that, when the tube containing syrup is immersed in water, the water *rises* through the syrup; if, on the other hand, the tube containing water is immersed in syrup, the water *descends* into the syrup; from which it follows that the thinner fluid passes through the thicker one, either from below or from above.

The force with which osmose acts is very great, the rush of the thinner fluid into the thicker one being in some cases sufficient to burst the bladder containing the latter. In like manner Hales ascertained that the sap rose with such force in the vine in spring as to counterbalance a column of mercury 38 inches in height, which is equal to 43 feet 3½ inches of water.[2]

That osmose forms an important adjunct to the circulation in plants is obvious from the fact that no plant can germinate without moisture, and a process of osmose must take place before water can be transmitted through

[1] Dutrochet states that we have constantly evidence of the simultaneous existence of the two opposite and unequal currents of endosmosis and exosmosis. It is not to be inferred from this that different fluids having the same density act with the same vigour when placed in an endosmometer and placed in water. All that is meant to be conveyed is, that the same fluids differing in density will produce like results when exposed to similar conditions, endosmosis being invariably accompanied by exosmosis. Dutrochet, speaking of fluids having the same density but differently constituted, says, "Sugar-water and gum-water of the same density being put successively into the same endosmometer, which is plunged into pure water, the former produces the endosmosis with a velocity as seventeen, and the latter with a velocity as eight only." Dutrochet has made experiments to show that an increase in temperature also increases endosmosis.

[2] Hales, vol. i. p. 124.

the cell-wall. "Water is required for the solution of the nutritive matter of the seed, as well as for inducing the endosmotic action of the cells: and no circulation nor movement of fluids can take place in the seed until water is taken up." De Candolle states that a French bean weighing $4\frac{1}{3}$ grains took up $6\frac{1}{2}$ grains of water during germination. The absorption of this large quantity of fluid is attended with an evolution of force which acts in specific directions according to the structure and condition of the parts at the time.

In artificial osmose one membrane and two fluids are usually employed. In natural osmose a variety of membranes and several fluids act and react upon each other.[1] In osmose there is no visible force at work, gravity being overcome by the thinner fluids nevertheless. In the same way, if a system of dry capillary tubes be arranged vertically in tiers, and have their extreme ends placed in water or other fluid, the fluid will rise more or less quickly into them. Here, again, we have a movement of fluids in opposition to gravity, no force being visible. A similar result is obtained if a leash of capillary tubes, or of hair glass or a strip of blotting-paper, be suspended vertically, and their lower extremities placed in water. This result I find is facilitated if the tubes and hair glass are arranged within a large tube, and if the blotting-paper be placed between slips of glass to prevent lateral evaporation. By keeping down lateral and promoting vertical evaporation, the fluid rises higher. A *vis a tergo* is therefore not necessary to a flow of sap in an upward direction. It suffices if the sap be supplied to a system of cells and vessels fitted to receive it. While the fluid is proceeding in the stem of the plant from below upwards, it is also disseminating itself laterally. This is necessitated by the porosity of the cells and vessels; any sap passing along or through them necessarily diffusing itself to a greater or less extent in its passage. It is in this way the transverse or cross circulation is accounted for. Ordinary capillary tubes form vessels with impermeable walls; the capillary tubes of nature, on the contrary, form vessels with permeable walls. The cases, although analogous, are not identical. It is necessary that the crude sap taken up from the earth traverse the plant in its length and breadth; and this, as I have endeavoured to show, can in a great measure be effected by the agency of natural laws, and without effort on the part of the plant or tree itself. From researches made by Goltz, it would appear that animal tissues have a similar power of absorbing and spreading a fluid from part to part quite irrespective of the force exercised by the heart in the general circulation. He ascertained this by detaching the heart from the circulation, and presenting strychnia to the tissues. Part of the tissues thus poisoned was administered to healthy frogs as food, and induced in all of them the phenomena characteristic of strychnia-poisoning.

FIG. 114.

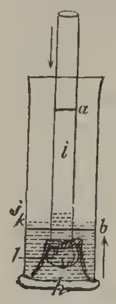


FIG. 115.

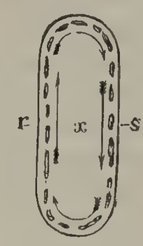


FIG. 116.

FIGS. 114 and 115.—Explain how endosmose may go on either from *below* or from *above*, according as the more tenuous fluid is placed lower or higher than the thicker fluid. In this experiment two tubes of exactly the same calibre are employed, the ends of the tubes (l, g) being covered with an animal or vegetable membrane. The tubes thus prepared are placed in glass vessels also of the same size. The tube i is filled with water until the water reaches the line a; the tube d being filled with syrup until the syrup reaches the line a; the vessel h (Fig. 115) is filled with syrup until it reaches the line b, the vessel c (Fig. 114) being filled with water until it reaches the line b likewise. When the thick and thin fluids so disposed are left for a short time, the thin fluid in the tube i (Fig. 115) descends by endosmose into the thicker fluid contained in the vessel h, until the thinner fluid reaches the point j, the thicker fluid rising from b to k; in like manner, the thin fluid contained in the vessel c (Fig. 114), ascends by endosmose into the thicker fluid in the tube d until the thicker fluid reaches the point e, the thinner fluid falling from b to f. This experiment proves that a thin or watery fluid may be made to pass through the tenacious fluids found in the interior of plants either from above or from below, according as the fluid is absorbed by the leaves or roots. Endosmose, as it were, pushes fluids into the plant; evaporation drawing them out (the Author, 1872).

FIG. 116.—x, Large cell with granular contents (r, s) gyrating. This figure shows how two forces may act on opposite sides of a circle or ovoid in opposite directions, and cause the cell or the contents of the cell to gyrate: *vide* arrows (the Author, 1872).

§ 98. Experiments to Show that the Vessels of Plants in Summer form Syphons.

When the leaves are fully formed in summer the circulation is more complex, but the same forces are at work. The leaves supply a rich anastomosis or network of vessels and structures, which Mr. Herbert Spencer is inclined to regard as absorbents. Similar absorbents are found in the stem and in the roots (see Figs. 104, 105, and 106). They join the vascular vessels together, and in this way convert them into what is practically a system of syphons, the extremities of which are directed alternately towards the leaves and roots. If a vigorous process of endosmosis goes on in one extremity of the syphon in connection with the root, a similar but opposite process goes on in the

[1] "Liquids are diffused throughout the whole plant by the action of cells and vessels having a different chemical constitution and different functions. One cell takes the juice from another, and acts by diffusion on the others. The cells of the rootlets imbibe by endosmose fluid matters which are carried into the stem, and the cells of the leaves by their exhaling functions aid in promoting a general movement of sap throughout the whole system." (Balfour's "Botany," p. 507.)

other extremity of the syphon, in connection with the leaf. The direction of the currents is, under the circumstances, reversed; but opposite forces may act on opposite sides of a circle and yet work in harmony. Fig. 116 and Fig. 117 will illustrate my meaning.

When the currents are united by loops pointing in opposite directions, and the two systems of syphons thus formed anastomose, a movement of the nutritious juices in a circle similar to what occurs in animals may be established. By placing the two systems of syphons together, we get a circulation which is continuous in the direction of the leaves and roots, and which is at the same time interrupted in both these directions. By this means the circulation may be quickened or slowed, according to circumstances.

This explains how the columns of moving fluids may be made to balance each other—to oscillate, or move on continuously in one direction for a certain period, and in another and opposite direction for another period. It also shows how the circulation may be influenced throughout its entire extent by an extraneous force applied at any part; how fluids may pervade the plant; how they may enter by the roots and escape by the leaves, or the reverse; how, similarly, cross currents may be established; and lastly, how the movements occurring in the lactiferous vessels and within individual cells may be explained.

It is in this way, too, that an excess of moisture in the ground or in the air may be made to pass through the plant in either direction; the excess of moisture in the ground passing up into the leaves, from which it is exhaled; the excess of moisture in the atmosphere entering at the leaves and escaping by the roots. There is nothing antagonistic in this arrangement. If an excess of moisture is absorbed by the root, say at *f* of Fig. 117, it passes in an upward direction, and escapes at *e*. If an excess of moisture is absorbed by the leaf, say at *c* of Fig. 117, it passes directly down to the root, as indicated by the dart, to *d*. In either case endosmosis is at work. When too much sap ascends from the root, it is endosmosis acting in an upward direction; when too much sap descends from the leaf, it is endosmosis acting in a downward direction. By placing the dense fluid above a less dense one, we get a brisk upward current; by placing the dense fluid below the less dense one, we get a brisk downward current. But when the osmotic currents are once established they may work in harmony; the upward current acting at *f* and the downward one at *c*, giving a continuous circulation of sap through the plant similar to the circulation in the trunk and other parts of animals. Nor is this all. It may even happen that when an endosmotic current, going in a certain direction, falls in with an exosmotic one having a similar direction, the two may blend and travel together. In this case the fluids fuse more or less completely *in transitu*—an arrangement which accounts for every form and variety of movement that can occur in plants.

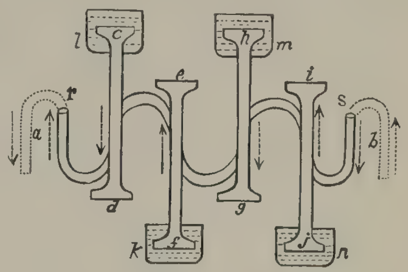


Fig. 117.

Fig. 117.—Compound syphon, with expanded absorbing and evaporating surfaces covered with animal or vegetable membrane to correspond with the roots and leaves of plants. Through this form of syphon (*a*, *b*), which essentially resembles that formed by the vessels (Fig. 110) and terminal vascular loops (Figs. 104, 105, and 106) of plants, fluids may be transmitted in advancing continuous waves (*vide* arrows), or made to oscillate. The peculiarity of this syphon consists in its being composed of a number of simple syphons united in such a manner that their free extremities are alternately directed downwards and upwards. The long legs of the simple syphon correspond to the expanded portions of the figure, and represent the leaves and roots of the plant, or, what is the same thing, its absorbing and evaporating surfaces. Any impulse communicated to the expanded portions, whether by absorption or evaporation, occasions a flow of fluid through the syphon, so that the circulation in plants is directly influenced by the presence or absence of moisture, heat, &c. *j*, *h*, *f*, *c*, Expanded absorbing surfaces covered with vegetable or animal membrane, and surrounded by water (*n*, *m*, *k*, *l*); *i*, *g*, *e*, *d*, similar evaporating surfaces. The absorbing and evaporating surfaces act together. Thus, at *j*, *h*, *f*, and *c*, absorption and endosmose are taking place (these may be regarded as pushing forces); whereas at *i*, *g*, *e*, *d*, evaporation is going on (this may be regarded as a pulling force). The arrows indicate the direction in which absorption and evaporation act. The different columns of fluid by this arrangement may be made to balance each other, as at *s*, *r*, or to flow in the direction *b*, *a*. The absorbing surfaces may all become evaporating surfaces, as in seasons of drought, or the evaporating surfaces may all become absorbing surfaces, as in rainy seasons. In the former case the plant is drained of its juices alike by leaves and roots; in the latter case the plant is gorged with sap through the same sources (the Author, 1872).

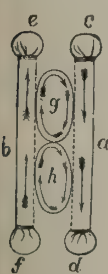


Fig. 118.

Fig. 118.—Diagram showing how intra-cellular circulation or gyration may be produced. *a*, *b*, Two vessels, the ends of which are covered with a portion of animal or vegetable membrane (*c*, *d*, *e*, *f*), to represent the absorbing or evaporating surfaces of plants. Between the vessels two vegetable cells (*g*, *h*) are placed. If water (say moisture from the earth) is applied at *f* to the thicker fluid (crude or other vegetable saps) contained in the vessel *b*, an endosmotic current sets in an upward direction towards *e*, as indicated by the arrows. If water (say moisture from the air, as rain or dew) is applied at *c* to the thicker fluid (crude or other vegetable saps) contained in the vessel *a*, an endosmotic current sets in a downward direction towards *d*, as indicated by the arrows. Similar currents are produced if evaporation goes on at the points *e* and *d*; or if absorption goes on at *f* and *c*, and evaporation at *d* and *e*. In either case the fluids passing through the vessels *a* and *b* wash and penetrate the sides of the cells *g*, *h* obliquely, and cause their contents to gyrate (*vide* arrows). A similar result is produced if the cells *g*, *h* are bathed with a thinner fluid than that which they contain, the endosmose and exosmose induced, aided by the rounded form of the cells, tending to rotation of the cell contents. The porosity of the walls of the cells and vessels favours these results. Absorption may be regarded as a pushing force; evaporation as a pulling force (the Author, 1872).

§ 99. Experiments bearing on the Intra-cellular Movements in Plants.

While the cells inaugurate or commence the general circulation, the general circulation in its turn influences the intra-cellular circulation. This follows, because when a current of fluid travels up the one side of a thin porous cell-wall, and another and opposite current travels down the other or opposite side, a certain proportion of the currents pass obliquely through the cell-wall, and cause the fluid contents of the cell to gyrate or move in a circle (Fig. 118). The cell contents are made to gyrate, even in the absence of opposing currents outside the cell, if endosmotic and exosmotic currents are induced within it; or if evaporation or capillarity be made to act at certain points (Figs. 111, 112, and 113).

The cell and vessel are part of a common stock, and both are influenced by the presence of moisture. The cell and vessel have their long axes running in the same direction, so that fluids entering and escaping from a cell and vessel by endosmose and exosmose produce movements in opposite directions; these movements, seeing the cell is closed and *rounded* at either end, being gradually converted into rotatory ones. The same holds true of the general circulation when the vessels are joined in the leaves and roots to form loops. Certain movements (not necessarily those of gyration) occurring within the cells inaugurate the general circulation, and, when the general circulation is established, it assists the gyration of the cell contents.

As the vessel is a differentiation of the cell, so the general circulation is a differentiation of the intra-cellular circulation.[1] The intra-cellular and general circulation in plants are referable to the same causes, and always act in harmony; the gyration of the cell contents within their capsule is equivalent to the gyration of the general circulation, when the vessels are joined by loops in the leaves and roots. The presence of vessels is not necessary to the circulation. This can be carried on in the inter-vascular spaces, or, indeed, wherever there are cavities or open canals along which fluids can travel.[2] In plants, fluids and air may circulate either separately or in combination. The syphon arrangement, fully described and illustrated by me in 1872,[3] accounts for the upward and downward growth of a plant, and for the fact that a stem may send out from its interior ascending shoots and leaves, and descending roots and spongioles—the former occasionally assuming the function of the latter, and *vice versâ*. A single system of vessels or tubes may act by itself and discharge a double function, or two systems may combine and discharge a single function. This arrangement supplies a circulation equal to the wants of every form and variety of plant. If the plant is simply cellular, the circulation is diffused, that is, the fluids enter the plant in all directions, and escape in all directions; every part of the plant being provided with nutritious juices, and every part being drained of effete matters. If the plant is provided with spiral and other vessels, with inter-cellular and other spaces, with lactiferous vessels, and with cells having a circulation of their own, the arrangement is equally simple and equally satisfactory as regards the circulation of nutritious juices in the stem and branches, and the absorption and discharge of fluids by the roots and leaves. The circulating forces in a plant are, so to speak, pitted against each other; the circulation is *in equilibrio*, and anything that disturbs this state of matters causes motion in one direction or another. Too much evaporation or too much absorption in the leaves, or too much moisture taken in or given off by the roots, or growth in a particular direction, may do this. The circulation is universal in its nature, and perfect of its kind. It can be made to slow and stop; to go on languidly or very vigorously; one part of it may be active while another is inactive; it is equal to all the demands made upon it by growth, by reproduction, by heat, by cold, light, and darkness; it is equally suited to the simple cellular plant, and the complex fibro-vascular one.

As the season advances, and the leaves become fully developed, the heat of summer comes into play. Evaporation now begins to take an active part in the circulation.[4] As the sap rises to the leaves, it is evaporated

[1] Henfrey is of opinion that intra-cellular movements take place in all cells at one period or other of their growth.

[2] Rainey was of opinion that the inter-cellular canals, which are more or less continuous throughout the entire length of the plant, are the channels through which the sap principally ascends; and Tetley was inclined to regard the cells and vessels as secreting organs which operated upon the crude sap in the inter-cellular canals, from which they separated, by vito-chemical actions, liquid and gaseous matters. The recent experiments of Hoffmann do not support this view. Rainey was further of opinion that the descent of the elaborated sap was through the vessels, and not through the cells or inter-cellular spaces. Schultz maintained that the sap descended through the lactiferous vessels, these being compared by Carpenter to the capillaries of animals. Herbert Spencer states from experiment that the spiral, annular, scalariform, and other vessels form the channels not only for the ascent, but also for the descent of the sap, the same vessels sufficing for both. There is thus much difference of opinion as to the precise course pursued by the ascending and descending saps.

[3] "The Physiology of the Circulation in Plants, in the Lower Animals, and in Man." (*Edinburgh Medical Journal*, 1872–73.)

[4] "In the leaves (and green portions of plants generally) the very important phenomenon of evaporation or transpiration of watery vapours occurs, and constitutes probably the most important agent of all in causing the supply and diffusion of food in plants. . . . In the spring, before the expansion of the buds, absorption is necessarily greater than transpiration; the water in such a case is stored in the stem, where it is made available for the expanding buds and growing tissues generally. In the summer, the transpiration is greater than the absorption: and then the leaves depend for their supply on the stores in the stem, or, failing that, they wither. Even in winter, provided the stem be not absolutely frozen, there is a motion of the juices dependent to a great extent on the temperature of the soil, which is always in that season higher than the air, and it increases in amount from the surface downwards. . . . The crude sap becomes more and more condensed as it ascends in the stem and other organs. In the leaves and other green parts it undergoes a most important transformation, loses by transpiration much of its water, and receives a new element in its composition, of the highest importance to it as material for development, namely, carbon, derived from the carbonic acid absorbed by the leaves, and decomposed there in sunlight, with the liberation of oxygen." (Henfrey's "Botany," pp. 567–569.)

in quantity from the stomata and other parts; these, when taken together, constituting a vast drying surface. The process which is now inaugurated can be exactly imitated by placing a glass tube in water, the upper end of which is slightly expanded, funnel-fashion, and covered with a layer of moist bladder. As evaporation goes on in the bladder, a continuous upward stream of fluid is furnished. The common spray-producer affords another illustration. In this very useful contrivance a capillary tube, or a tube with a capillary point, is placed in fluid, a corresponding tube being arranged to meet its upper end at right angles. A current of air forced through the second tube causes the fluid to rise in the first tube, an effect favoured by capillary attraction when the tube is small.[1] The sap in summer, from evaporation and the elaboration it undergoes in the leaves, is rendered more tenacious, and adheres with greater force to the vessels and channels through which it passes. As a consequence, there is a slight increase in the amount of capillary action, and a slight diminution of the osmotic action. The vital capillary and osmotic forces vary in intensity, the one being weaker when the other is stronger, and *vice versâ*.[2]

The *succus proprius*, when elaborated, descends into the growing parts of the tree according to demand, and at a varying speed. It goes from a higher to a lower level; not, however, in obedience to the law of gravitation, for it is found that if a branch is bent to the ground, the *succus proprius* actually ascends prior to descending. Gravity may, under certain circumstances, arrest, instead of cause, the flow of a fluid; and atmospheric pressure will cause water to flow into an exhausted receiver.[3] Petit Thouars and Gaudichaud, as I have explained, believe that the embryo of plants consists of two systems—a caulinary and radicular system; the former having an ascending circulation, and tending to develop buds and leaves; the latter having a descending circulation, and tending to develop the stem and roots—each system having cells and vessels peculiar to itself.[4] Many are of opinion that the two systems persist throughout the entire life of the plant. This view is favoured by the growth of plants in an upward direction, and by the presence in screw-pines of adventitious and other roots which grow downwards into the soil (Figs. 83 and 84). This growth in opposite directions implies two systems, and a reverse circulation. Mr. Herbert Spencer takes an opposite view. He maintains that the two sets of vessels cannot be demonstrated to exist, and that in reality there is only one set, the fluids oscillating therein in such a manner as at one period to occasion an upward circulation to the leaves, and at another a downward circulation to the roots; the vessels, according to him, terminating in the leaves and roots in a series of club-shaped expansions, which he claims to have been the first to discover and describe (Figs. 104, 105, and 106).[5]

§ 100. Absorbents of Plants.

The club-shaped expansions do not occur in all leaves, and are found in stems and branches that have assumed the function of leaves. They occupy the inter-cellular spaces between the ultimate venous network of the leaves, into which network they also open. Some of them, however, open outwards towards the air. The vascular club-shaped expansions are thus brought into immediate contact not only with the veins of the leaf, but also the tissues concerned in assimilation. They are found in a less developed form in the root and body of the turnip. The simplest kinds, according to Mr. Spencer, consist of only fenestrated cells, with their ends bent round so as to meet. "It should be added that, while the expanded free extremities graduate into tapering free extremities, not differing from ordinary vessels, they also pass insensibly into the ordinary inosculations. Occasionally, along with numerous free endings, there occur loops, and from such loops there are transitions to the ultimate meshes of the veins." By the club-shaped expansions a direct connection is established in the leaf between the vascular tubes found in the branches, stems, and roots; in fact, the free extremities of the tubes may be said to be united in the leaves

[1] In Professor (now Lord) Lister's spray-producer, the second tube is made to bifurcate—one portion descending into the bottle containing the fluid, which it is not allowed to touch; the other ascending and meeting the point of the first tube at right angles, as before. In this case the current of air introduced into the second tube forces the fluid through the first tube, and breaks it up into spray simultaneously. The cloud of spray produced by this most ingenious instrument is remarkable alike for its great size and the extreme state of division to which its component particles are reduced.

[2] "The entrance of fluid into a plant may be explained by endosmose and certain vital affinities; the escape by exosmose and certain vital repulsions." (Gyde, "On Radical Excretions," *Trans. High. and Agric. Soc.*, Oct. 1843, p. 273.)

[3] Grove, "On the Correlation of Physical Forces," p. 10.

[4] "In the embryo of a flowering plant it is scarcely possible to define the limits even of the stem itself, which loses itself above in the plumule, and below in the radicle." (Henfrey's "Botany," p. 23.)

[5] These structures, when present, form the terminations of the vascular system. They are masses of irregular and imperfectly-united fibrous cells, such as those out of which vessels are developed; and they are sometimes slender and sometimes bulky—usually, however, being more or less club-shaped. Speaking of the club-shaped expansion of the *Euphorbia neriifolia*, Mr. Spencer says, "Occupying one of the interspaces of the ultimate venous network, it consists of a spirally-lined duct, or set of ducts, which connects with the neighbouring vein a cluster of half-reticulated, half-scalariferous cells. These cells have projections, many of them tapering, that insert themselves into the adjacent inter-cellular spaces, thus producing an extensive surface of contact between the organ and the embedding tissues. A further trait is that the unsheathing prosenchyma is either but little developed or wholly absent, and consequently this expanded vascular structure, especially at its end, comes immediately in contact with the tissues concerned in assimilation." Further on he observes, "Considering the structure and position of these organs, as well as the nature of the plants possessing them, may we not form a shrewd suspicion as to their function? Is it not probable that they facilitate absorption of the juices carried back from the leaf for the nutrition of the stem and roots?" ("Principles of Biology," vol. ii. p. 559.)

and roots by a series of vascular expansions resembling the capillary vessels of animals. If this be so—which seems reasonable—many of the difficulties connected with the circulation in plants disappear, for the presence of a capillary system in the leaves and roots enables us to reconcile the double set of vessels of Petit Thouars and Gaudichaud with the single set of Mr. Spencer. It also enables us to explain the ascending current in spring, the ascending and descending currents in summer, and the descending current in autumn. Further, it shows how those currents may be inaugurated, how carried on, how interrupted, and how partly or altogether stopped. In the root one set of cells and vessels absorb and another excrete, the excreting vessels, according to Macaire,[1] giving off matters which are detrimental to the soil. In this arrangement we have an indication of two systems and two forces acting in opposite directions (Fig. 82).

Whether two distinct systems of vessels exist is immaterial, if, as I have explained, all vessels virtually form syphon tubes. The vessels which convey the sap, as is well known, are arranged in more or less parallel vertical lines. If the vessels are united to each other by a capillary plexus, or what is equivalent thereto, in the leaves and roots, they are at once, as has been shown, converted into syphon tubes; one set bending upon itself in the leaves, the other set bending upon itself in the roots. As, however, a certain proportion of the syphon tubes which bend upon themselves in the leaves are porous and virtually open towards the roots; while a certain proportion of the syphon tubes which bend upon themselves in the roots are porous and virtually open towards the leaves; it follows that the contents of the syphon tubes may be made to move by an increase or decrease of moisture, heat, &c., either from above or from below. In spring, the vessels may be said to consist of one set, because at this period the leaves and the connecting plexuses which they contain do not exist. All the vessels at this period may therefore be regarded as carrying sap in an upward direction to form shoots, buds, and leaves, part of the sap escaping laterally because of the porosity of the vessels. In summer, when the leaves are fully formed, the connecting links are supplied by the capillary vascular expansions formed in them—the tubes are, in fact, converted into syphons. As both extremities of the syphons are full of sap in spring and early summer, an upward and a downward current is immediately established. When the downward current has nourished the plant and stored up its starch granules for the ensuing spring, the leaves fall, the syphon structure and action are interrupted, and all the tubes (they are a second time single tubes) convey moisture from above downwards, as happens in autumn. As the vascular expansions or networks are found also in the stems of plants, it may be taken for granted that certain of the tubes are united in spring, the upward rush of sap being followed by a slight downward current, as happens in endosmose and exosmose. As, moreover, the spongioles of the root and the leaves are analogous structures, and certain vessels are united in the roots, the downward current in autumn is accompanied by a slight upward current. This accounts for the fact that, at all periods of the year, the upward, downward, and transverse currents exist; the upward and downward currents being most vigorous in spring and autumn, and scarcely perceptible in winter. Furthermore, as some of the vascular expansions in the leaves are free to absorb moisture, &c., in the same way that the spongioles are, it follows that the general circulation may receive an impulse from the leaves, or from the roots, or both together, the circulation going on in a continuous current in certain vessels, as explained (see Fig. 117).

§ 101. Analogy between Leaves and Roots.

It only remains to add that, in dealing with the several kinds of circulation in plants, nature has exercised the most extraordinary vital and physical powers. It has suppressed at one time, and when desirable, the universal law of gravitation, but it, at another time, has called to its aid such of the physical forces as suits its purpose. It has, moreover, mixed up and blended with the utmost precision the vital and physical forces when anything is to be gained from such a procedure. The great First Cause has laid the organic and inorganic kingdoms under contribution in this and other ways. Nothing can possibly exceed the fine balancing of the vital and physical forces, or the beautiful structural arrangements by which the balancing and other results are brought into operation. A tree growing upwards acts in opposition to gravitation. The same is true of the endosmotic current which carries sap from the root upwards. Capillarity, adhesion, and repulsion also act in opposition to gravitation, but all the forces (those of life included) work harmoniously together when anything is to be gained by the combination. Life is the superior directive agency, and it selects whatever matter and force seem best suited to attain its ends. The forces are marshalled and dissipated not by chance but by premeditation and design. As a matter of fact the arrangements alluded to are under control and fundamental. They form part of the forces which control the inorganic and organic kingdoms in their entirety. That leaves and roots have many points in common was shown by the researches of Bonnet,[2] who found that plants of mercurialis whose leaves were in contact with

[1] Macaire-Princeps, "Sur les Excrétions des Racines," *Mém. de la Soc. Phys. et d'Hist. Nat. de Genéva*, tom. v. p. 287. *Annales des Sc. Nat.*, 1st series, xxxviii. 402. Brugmars, "De Mutata Humorum in Regno Organico Indole."

[2] Bonnet, "Recherches sur l'Usage des Feuilles dans les Plants." Gottingen, 1754.

water absorbed as much, and, for a time, kept nearly as fresh, as those whose roots were immersed.[1] The hairs on the under surface of leaves absorb moisture, and seem to act as cellular rootlets. Nor is this all. Hoffmann [2] showed that, after every fall of rain or dew, the leaves absorbed moisture, which passed downwards in the tracheæ and enveloping prosenchyma, and displaced for a time the air usually found in the spiral vessels. In proportion as the absorption was abundant and rapid, the tendency of the moisture to enter the spiral vessels was increased. Almost precisely the same remarks might be made regarding the spongioles of the root. In seasons of drought they absorb and transmit comparatively little moisture. After a rainfall the spongioles drink greedily, and send on crude sap in abundance. Further, excess of moisture sent up by the roots is exhaled by the leaves; excess of moisture, sent down by the leaves, escaping by the roots. If the relation existing between the leaves and roots be disturbed, and exhalation prevented, the plant becomes dropsical. If, on the other hand, the exhalation from the leaves be in excess of the moisture absorbed by the roots, the leaves wither and droop. Leaves and roots both give off gases—the former, oxygen; the latter, according to Wiegmann and Polodorff, carbonic acid. In the epiphytes, or air-growing plants, the roots (aërial of course) are of a green colour, like the leaves, and possess stomata. The stomata are wanting in the roots of aquatic plants, but they are also absent in the submerged leaves. The cuttings of many plants give off *leaf-buds and roots* at the same time. "In the monocotyledons and ferns, the radicle is abortive, and the efficient roots are really lateral organs, comparable in a certain way to the leaves upon the ascending part of the stem." [3] When the branches and leaves are growing rapidly, the roots are also developing their rootlets, and constantly renewing their delicate absorbing extremities. Aërial roots take on the function of leaves, and obtain nourishment from the atmosphere. In this case they lose their fibrils, assume the appearance of stems, and throw out leaf-buds.

Duhamel proved this ingeniously and very simply. He took a willow and inserted its branches into the soil, where they took root. This done, he pulled up the original root and exposed it to the air. The original root, after a short interval, became transformed into *leaf*-bearing branches. A curious case is related where an apple-tree was undermined by a flood and fell into the river; its branches becoming imbedded in the mud of the river while its roots were elevated and exposed to the air. In time, buds, branches, and leaves emerged from the roots, and ultimately produced a crop of fruit. The fibrous rootlets upon the surface of tuberous taproots, like the carrot, parsnip, &c., appear to be mostly *true branches*.[4] Speaking generally, it seems to be a matter of little consequence whether the stem be placed in a vertical or procumbent position. In either case the branches and leaves strike upwards—the roots and spongioles downwards. Roots, like leaves, are sometimes spirally arranged. Roots may produce buds, as shown in the *Anemone japonica*, and branches may be made to throw out rootlets. The rhizome of Solomon's-seal throws out a bud from its upper surface, and roots from its under; and the strawberry, from its runners, sends leaves up and roots down,[5] all which proves very clearly that the spongioles and leaves, and roots and branches, are closely allied both in structure and function—the circulation and the forces which produce it being in either case essentially the same. The intimate relation which exists between the roots and the leaves is well expressed by Mulder, who asserts that all the nitrogenous constituents of plants are absorbed by *the roots* and assimilated there at once, carbon being fixed by the *green organs*; that a continual interchange goes on *from above and from below* between *the leaves and roots*, the roots supplying protoplasmic material which originates all organic phenomena; the leaves on their part sending down the ternary compounds (CHO), which supply the material for cell-membranes, starch, &c. The leaves of plants have the power of attracting and condensing the moisture suspended in the air, and the roots *can pump it up* from the soil from considerable depths. A tree has, as it were, open mouths at both ends; these mouths communicating with open channels, which, in some cases, traverse the entire length of the tree; at other times they interlace and form loops, which convert them into syphons directed towards the leaves and roots respectively, as already stated (Fig. 117).

§ 102. The Effects produced on the Circulation by the Swaying of Plants in the Wind: Mr. Herbert Spencer's Views.

Mr. Spencer is of opinion that the circulation is influenced to a considerable extent by the swaying of plants and trees in the wind; this oscillation subjecting certain parts of the tree or plant to lateral and longitudinal strain.

[1] "Leaves proceed from the nodes of the axis, and commence as *cellular processes at the extremities of the medullary rays*. The extremities of the roots are composed of *loose cells, which appear to be the terminal tissues of the radicle*, and formed by the elongating root." ("Balfour's Botany," pp. 51 and 96.) Both leaves and roots are covered by epidermis, and have vessels developed in them. The stomata of the leaves seem to be represented in the roots by hairs. Leaves frequently display hairs, and the stomata are generally absent in submerged leaves.

[2] "On the Circulation of the Sap in Plants," in "Scientific Memoirs," *Nat. Hist.* i. p. 46.

[3] Henfrey's "Botany," p. 16.

[4] Ibid., pp. 16–18.

[5] "The strawberry plant produces in the axils of its leaves, buds, which in the same season expand several of their internodes and form long filiform branches, the buds of which give rise to rosettes of leaves and stock root, and thus form independent plants." (Ibid., p. 33.)

The effect of the strain, he remarks, is to bend the tree or plant alternately in opposite directions, and from the parts so bent the sap is driven in an upward and downward direction, a certain amount being forced through the coats of the vessels (which are porous) into the surrounding tissues. According to him, a certain proportion of the propelling power is intermittent, confined to no locality, and variable as to intensity.

To reconcile the idea of an upward and downward circulation in a single system of vertical tubes, he explains, as has been stated, that the vessels of the stem and branches terminate in club-shaped expansions in the leaves; which expansions act as absorbent organs, and may be compared to the spongioles of the root. If, therefore, the spongioles of the root, he argues, send up the *crude* sap, it is not difficult to understand how the spongioles of the leaf (the club-shaped expansions referred to) send down the *elaborated* sap, one channel sufficing for the transit of both.

From the foregoing, it will be evident that, in Mr. Spencer's opinion, the upward and downward currents take place in different parts of the same tube, and that when one part of the tube is engaged with the up circulation, the down circulation is prevented, and *vice versâ*.[1] Now, granting that the upward and downward currents take place in the same tube, it appears to me that both currents may be going on at the same time by a simple process of endosmose and exosmose.[2] I have difficulty in understanding how, in an organised structure, the saps should be driven about in a reckless manner, at irregular intervals, and as it were by accident. I can, however, readily comprehend how, if a porous vertical tube, or any number of such tubes, containing dense fluids, be arranged in parallel lines, and placed in contact with less dense fluids, the less dense fluids will penetrate the more dense ones in an upward or downward direction, according as the less dense fluids are placed below or above the more dense fluids; the more dense fluids penetrating the less dense fluids always in an opposite direction, so as to produce two distinct and opposite currents, which run from below upwards and from above downwards; the porosity of the vessel occasioning a certain amount of transfusion or lateral circulation. In this we have an arrangement capable of furnishing a steady supply of sap to every part of the tree, quite irrespective of any influence exerted by the wind. In fact, it is necessary to exclude the action of the wind when discussing the question; for sap ascends, descends, and transudes in trees nailed to walls, in climbing and hothouse plants, where of course the wind is inoperative. Mr. Spencer's argument may be briefly stated. "If," he says, "a trunk, a bough, a shoot, or a petiole is bent by a gust of wind, the substance of its convex side is subject to longitudinal tension, the substance of its concave side being at the same time compressed. This is the primary mechanical effect. There is, however, a second mechanical effect, which more chiefly concerns us. That bend by which the tissues of the convex side are stretched also produces lateral compression of them. It is demonstrable that the tension of the outer layer of a mass made convex by bending must, by composition of forces, produce at every point a resultant at right angles to the layers beneath it; that, similarly, the joint tension of these two layers must throw a pressure on the next deeper layer, and so on. Hence, if at some little distance beneath the surface of a stem, twig, or leaf-stalk, there exist longitudinal tubes, these tubes must be squeezed each time the side of the branch they are placed on becomes convex. If, then, the sap-vessels are thus compressed, the sap contained by them will move along the lines of least resistance. Part, and probably the greater part, will escape lengthways from the place of greatest pressure; some of it being expelled downwards, and some of it upwards. But, at the same time, part of it will be likely to ooze through the walls of the tubes. If these walls are so perfect as to permit the passage of liquid only by osmose, it may still be inferred that the osmose will increase under pressure; and probably, under recurrent pressure, the places at which the osmotic current passes most readily will become more and more permeable, until they eventually form pores. At any rate, it is manifest that when pores and slits exist, whether thus formed, or formed in any other way, the escape of sap into the adjacent tissue at each bend will become easy and rapid. The lateral oscillation or strain takes place in stems and branches, a longitudinal strain occurring in roots, the circulation being in part due to a rude pumping process, occasioned by the swinging about of different parts of the tree or plant." On this doctrine Mr. Spencer founds another, namely, that in the region of the strained part, a profuse exudation of sap takes place; this sap going to form woody fibre, which strengthens the yielding part. Unfortunately for Mr. Spencer's hypothesis, the upward, downward, and transverse currents, as has been stated, occur in hothouse and other plants, and in roots which are in no way exposed to winds; wood being formed under these circumstances just as it is out of doors. Indeed, wood is formed in trees nailed firmly to a wall, and in climbing

[1] Mr. Spencer observes: "If, then, returning to the general argument, we conclude that these expanded terminations of the vascular system in leaves are absorbent organs, we find a farther confirmation of the views set forth respecting the alternating movement of the sap along the same channels. These spongioles of the leaves, like the spongioles of the root, being appliances by which liquid is taken up to be carried into the mass of the plant, we are obliged to regard the vessels which end in these spongioles of the leaves as being the channels of the down current whenever it is produced. If the elaborated sap is abstracted from the leaves by these absorbents, then we have no alternative but to suppose that, having entered the vascular system, the elaborated sap descends through it. And seeing how, by the help of these special terminations, it becomes possible for the same vessels to carry back a quality of sap unlike that which they bring up, we are enabled to understand tolerably well how this rhythmical movement produces a downward transfer of materials for growth." ("Principles of Biology," vol. ii. p. 561.)

[2] Dutrochet believes that in endosmosis the two opposite fluids pass through the same capillary canal, the one travelling in one direction, the other in a contrary direction; and that the double movement of transmission takes place by a reciprocal penetration of the two fluids.

plants which twist themselves around unyielding structures. Nuts and thorns, and other hard structures, in like manner, are formed in the absence of anything in the shape of strains. Mr. Spencer states that in plants with stems, petioles, and leaves, having tolerably constant attitudes, the increasing porosity of the tubes, and consequent deposit of dense tissue, takes place *in anticipation* of the strains to which the parts of the individual are liable, but takes place at parts which have been habitually subject to such strains in ancestral individuals. If, however, the sap is exuded, and wood formed, before the strain takes place, the strain cannot consistently be regarded as the cause either of the exudation or of the wood. While attaching considerable importance to the effect produced on the circulation by the swaying of plants and trees in the wind, it must be stated that Mr. Spencer gives due prominence to the capillary and osmotic forces. He writes: "The *causes* of circulation are those actions only which disturb the liquid equilibrium in a plant by permanently abstracting water or sap from some part of it; and of these the first is the absorption of materials for the formation of new tissue in growing parts; the second is the loss by evaporation, mainly through adult leaves; and the third is the loss by extravasation through compressed vessels. Only so far as it produces this last can mechanical strain be regarded as truly a cause of circulation. All the other actions concerned must be classed as *aids* to circulation—as facilitating that redistribution of liquid that continually restores the equilibrium continually disturbed; and of these capillary action may be named as the first, osmose as the second, and the propulsive effect of mechanical strains as the third." [1]

§ 103. Epitome of the Forces engaged in the Circulation in Plants.

Before passing to a consideration of the circulation as it exists in animals, it may be useful to recapitulate very briefly the forces at work in the circulation in plants and to say a few words with regard to the nature of force generally. Of the forces which produce the circulation in plants, capillarity and osmose undoubtedly perform a chief part. Capillarity inaugurates and osmose maintains in a great measure, not only the ascending and descending currents, but also the cross currents and the gyration or rotation of the cell contents. Capillary action is induced in an upward or downward direction according as the fluid is presented to the top or bottom of the capillary tube. It may go on either within the vessels of the plant or in the interspaces between the vessels; and the same may be said of endosmose and exosmose. Endosmose, as has been explained, acts in conjunction with exosmose. The one implies the other. The endosmotic and capillary actions are modified by vital, chemical, and other changes. They produce a swelling of the cells and entire tissues of the plant, as the fluid absorbed by the roots and leaves must be accommodated within the plant. The fluids imbibed produce pressure of the cell-walls, vessels, &c.—these reacting and forcing the fluids in the direction of least resistance. Increase of temperature in the roots, stem, and branches leads to a similar result; increase of temperature expanding the air which pervades all parts of plants. The expanded air, like the fluids, naturally escapes in the direction of least resistance. From this it follows that the circulation is most vigorous during the day, and least so during the night. The processes of growth and reproduction produce the vacuum into which the fluids urged on by cell, air, and other pressure naturally flow. The presence of sap and air is equally necessary to germinating and growing plants. Growth or vital change involves chemical change. Starch is to be transformed into sugar, and before this can be done, water must flow to the point where the transformation is to take place; the demand for water acts as a *vis a fronte*. The leaves exhale from their surfaces, and here, too, a constant evaporation is going on. A fluid abstracted from the leaves by external heat draws on the fluid in the branches; the fluid in the branches drawing up that in the stem, which, in turn, acts upon that in the roots; the roots being originally supplied by absorption, capillarity, and osmose. This can be proved by direct experiment. If a system of capillary tubes have their lower extremities placed in water, while a portion of moistened bladder is laid across their upper extremities, expanded to receive it, it is found that the quantity of fluid which passes through the tubes is determined by the amount of evaporation. The roots exhale as well as absorb, so that a certain proportion of the fluids are drawn downwards. In other words, the leaves may be said to draw the fluids upwards, while the roots, at stated periods, draw them downwards. The leaves act more especially in conjunction with endosmose, the roots with exosmose. These, again, act in harmony with capillary structures and vito-chemical changes incident to growing plants.

Lastly, the occasional swaying of petioles, branches, and stems by the wind exerts, as Mr. Herbert Spencer has shown, an intermittent pressure, to which he attributes an upward, downward, and lateral thrusting of the sap in the direction of least resistance. The strain to which the different parts of the tree are subjected by the swaying in question gives rise, as he explains, to an exudation of sap at the strained point—the exuded fluids making room for other fluids, which, being supplied either by the roots or leaves, result in motion.

I have placed the lateral swaying or pumping process of Mr. Herbert Spencer last, because, as has been already stated, the general and intra-cellular circulation of plants can go on when no wind is present.

[1] "Principles of Biology," vol. i. pp. 553, 554.

Considerable diversity of opinion exists as to the channels through which the circulating fluids of plants are conveyed. Hoffmann and Unger maintain that in plants possessed of fibro-vascular bundles, the sap in the first instance passes up from the roots chiefly in the parenchymatous cellular constituents of the bundles, and that these juices do not pass by the spiral vessels themselves.

Rainey was of opinion that the inter-cellular canals, which are more or less continuous throughout the entire length of the plant, are the channels through which the sap principally ascends; and that the descent of the elaborated sap occurs in the vessels, and not in the cells or inter-cellular spaces. Tetley was inclined to regard the cells and vessels as secreting organs which operated upon the crude sap in the inter-cellular canals, from which they separated, by vito-chemical actions, liquid and gaseous matters. Schultz maintained that the sap descends through the lactiferous vessels, these being compared by Carpenter to the capillaries of animals. Spencer states from experiment that the spiral, annular, scalariform, and other vessels, form the channels for the ascent of the sap, and he is disposed to believe that the sap descends in the same vessels in which it ascends.

He is further of opinion that there is only one system of vessels, the crude and elaborated saps ascending and descending in the same vessels at different times, a result favoured, but not caused, by the swaying of the different parts of the plant or tree in the wind. He is quite aware that the ascent and descent of the sap are not occasioned by the swaying referred to, for he remarks, "Whether there is oscillation or whether there is not, the physiological demands of the different parts of the plant determine the direction of the current."[1] The researches of Petit Thouars, Gaudichaud, De la Hire, Darwin, Knight, and Macaire, favour the idea of a double system of vessels—an ascending and a descending set. However authors differ as to the number and direction of the vessels, they are all agreed in this, that the currents ascend, descend, and transude. The question which naturally presents itself at this stage is, Are vessels necessary to the circulation in plants? and if so, are there one or two sets of vessels? I pointed out that vessels are not necessary to the circulation, as this goes on in cellular plants where no vessels exist. I also endeavoured to show that when vessels are present, the circulation may go on either within them, or in the inter-vascular spaces outside of them, provided these, like the vessels, are capillary in their nature. I further attempted to reconcile the views of those who maintain that there is only one set of vessels, with those who believe that two sets are necessary for carrying on the ascending and descending currents, by supposing (and we have good warrant for the supposition) that the vessels and inter-vascular spaces of plants are united in the stem and branches, and at certain periods of the year in the leaves and roots, to form syphons, the free extremities of which are turned alternately in the direction of the leaves and roots. These syphons are infinite in variety and form, and interlace in every conceivable direction. They may be confined to the roots, stem, branches, or leaves, or portions of them, the fluids being sent on by relays; or they may extend throughout the entire length of the plant or tree. They consist of rigid capillary tubes with porous walls, that is, walls capable of preventing the ingress of air, while they do not prevent the free ingress and egress of fluids, as witnessed in osmose and evaporation. The long legs of the syphons, or what are equivalent thereto, correspond to the evaporating surfaces, and those surfaces in which an active osmose is established. The leaves and roots form such surfaces, but they are not confined to those portions of the plant, as they exist in every part of it; the plant breathing and drinking at every pore when it has an opportunity. If the vast drying or evaporating surfaces furnished by a tree in full leaf be taken into account, the immense tractile power exerted, and the astonishing force with which the fluids are drawn up in the syphon tubes referred to, will be readily understood. If, on the other hand, the leaves and roots be regarded not as evaporating surfaces, but as absorbing surfaces (they are both), that is, surfaces capable of imbibing moisture, no difficulty will be experienced in understanding that the force exerted by endosmose, which is a pushing force, is equally great. But evaporation and endosmose—in other words, the tractile or *pulling* force, and the propelling or *pushing* force—can, by the syphon arrangement, act together; the one operating upon the one leg of the syphon, the other upon the remaining leg, in such a manner as to cause a continuous flow of fluids through the syphon. It is thus that evaporation and absorption can go on together, and that fluids, or fluids and air, may be made to circulate together. The nutritive juices may be said to invade the tissues of the plant by a process of endosmose, the endosmotic action being favoured by evaporation and transpiration; endosmose pushing and evaporation pulling and giving the fluids right of way through the tissues. No better arrangement can be imagined for the supply of new material and the discharge of effete matter. The tissues are literally irrigated and washed out at the same time.

Precisely the same remarks may be made regarding the animal tissues. It is an error to suppose that the circulation in animals is carried on exclusively by the heart. This is an engine employed for carrying the blood to and from the tissues over considerable distances, but the tissues do their own work, or rather the particles of the tissues are so arranged that they permit certain physical forces, such as capillary attraction, osmose, evapora-

[1] "Principles of Biology," vol. i. p. 557.

tion, respiration, chemical affinity, &c., largely to do the work for them. The organic kingdom avails itself of inorganic power. This may account for the great rapidity with which poisons spread in animal organisms, and also for their mode of elimination. The capillary vessels of animals form syphon loops, as in plants, and the animal syphon loops are porous in the same sense that the vegetable syphon loops are porous. They are, therefore, capable of transmitting a continuous stream of fluid in a given direction, and of absorbing and evaporating at innumerable points—the absorption and evaporation, as already explained, greatly facilitating instead of retarding the general circulation. The interiors of plants and animals when the circulation is normal, and its constituent parts in full working order, present a scene of unparalled activity. It far transcends that witnessed in the nest of the ant or the hive of the bee, the multiplicity of the operations of which have come to be regarded as the centres of industry. That the tissues respire has been abundantly proved by the researches of Spallanzani. He found that all the tissues take in oxygen and give off carbonic acid, as the lungs themselves do. The view here advocated is further favoured by the fact that the circulation in animals does not cease the moment the body dies and the action of the heart fails. On the contrary, the tissues draw on the fluids, these being evaporated as before — an arrangement which accounts for the arteries being comparatively void of blood after death, the blood by this process being actually diminished in amount; diminished, because after the death of the body no new blood is being formed, while the old blood is being circulated and used by the tissues so long as the tissues retain their vitality and heat. That the heart is not necessary to the circulation, in its widest sense, is proved by the fact that it goes on when neither heart nor blood-vessels are present. The heart, therefore, while the major factor in the circulation in animals, may, after all, be regarded as an auxiliary, that is, a differentiation for a purpose. It is found that in criminals executed by hanging, the heart beats regularly for a quarter of an hour after death, during which period it is possible to make sphygmographic tracings of its action. But to return. I was engaged in discussing the syphons and syphon action in plants.

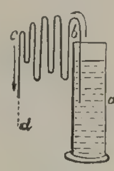


FIG. 119.

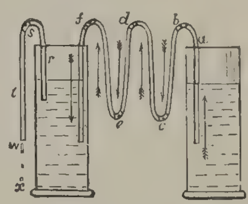


FIG. 120.

FIG. 119.—Capillary compound syphon, similar to that found in the interior of plants. The capillary syphon differs from the ordinary syphon in this, that the point at which the fluid escapes *may be much higher* than that at which it enters. Thus the fluid may enter at *a*, and escape at *c*, instead of at *d*. The instant the end of the syphon *b* is placed in the fluid, the fluid rises and falls, and travels in the direction *c*, finally escaping at *d*. The compound capillary syphon here figured is equally effective when inverted, the fluid being applied from above instead of from beneath. The compound capillary syphon explains within certain limits the circulation as it exists in plants with well-defined vessels and inter-vascular spaces (the Author, 1872).

FIG. 120.—Simple and compound syphons perforated at various points; the perforations being covered with animal or vegetable membrane, to prevent the ingress of air, while they do not prevent the ingress or egress of fluids by absorption and evaporation. *r*, Short leg of simple syphon; *t*, long leg of simple syphon; *s*, perforation covered with membrane; *w*, *x*, fluids escaping through the syphon; *a*, compound syphon, the legs of which are of the same length; *b*, *c*, *d*, *e*, *f*, perforations in compound syphon covered with membrane. By elevating the vessel to the right of the figure, the fluid contained within the syphon is made to pass through it, as indicated by the arrows, into the vessel to the left of the figure. (This process may be reversed.) Evaporation or absorption occurring at the points *b*, *c*, *d*, *e*, *f*, facilitates the transmission of fluids through the syphon. They even generate the movement referred to; the fluids oscillating now in one direction, now in another, according as one or other prevails. The compound syphon may have its legs of the same length, or the one leg long and the other short, as in the simple syphon. The apertures covered with membrane give the unequal pressure required to produce a true syphon action. These apertures correspond to the leaves, roots, and other surfaces of plants, in which absorption, evaporation, and other physical actions go on (the Author, 1872).

The syphons in plants are sometimes simple, sometimes compound. By the term simple, I mean a syphon consisting of a tube bent upon itself, the one extremity of which is longer than the other (Fig. 120, *r*, *t*). By the term compound syphon I mean a syphon consisting of several syphons united to each other, the limbs of which are not necessarily unequal in length. The compound syphon may be composed of rigid non-porous capillary tubes, as shown at Fig. 119; or of larger tubes with porous walls, as seen at Fig. 120.[1] When a series of syphons turned in opposite directions are united and open into each other, the circulation becomes more or less continuous, as in animals. Under these circumstances a certain proportion of the syphons are open in the direction of the leaves and roots. When I use the term "open," I wish it to be understood as "open" in the sense that they can take in fluids by imbibition or absorption, or give them off by evaporation.

In such a system of syphons, a true syphon action can be induced and maintained; the vegetable membrane or aggregation of cells, which closes the ends of the syphons, effectually preventing the admission of air from without, but not interfering in the slightest with the passage of fluids from without or from within—in other words, with absorption and evaporation.

In the compound capillary syphon (Fig. 119), I find that the moment the one end of it (*a*) is immersed, the fluid fills the several loops of which it is composed, and escapes by the extremity not immersed (*d*). In this case the compound syphon arrangement which I believe exists in plants is nearly but not exactly imitated. The syphons

[1] The walls in this case may be flexible as well as porous, made of gut, supported with wire.

in trees have porous walls in addition to their free, partially open, porous extremities. By porous walls, I mean walls which admit of the passage of fluids through them.

In the compound syphon represented at Fig. 120, the several conditions found in plants are, I apprehend, exactly reproduced. Here we have a syphon made of glass tube with numerous apertures in it. These apertures are of large size, and covered with bladder. They admit of a free evaporation or a free absorption at a great many points. As, however, they are covered with an animal membrane, no air is permitted to enter the syphon to disturb its action.

In the novel form of syphon which I have here constructed, fluids and air, if need be, can pass on in rapid and uninterrupted succession; evaporation taking place, and fluids being added at different portions of the syphon, in such a manner as not only not to interfere with the well-known action of the syphon, but, what is very remarkable, actually to favour it. I showed on a previous occasion that if a capillary tube placed in water be expanded at one end and covered with bladder, the fluid rises in the tube in proportion to the evaporation going on in the bladder. I also drew attention to the fact, that evaporation may go on either from above or from below, that is, in the leaves or roots. When evaporation (as in seasons of drought) goes on at both ends of a plant, the fluids contained within the plant are drawn in opposite directions; counter currents being thus established which speedily drain the tree of its juices and cause it to exhibit symptoms of collapse—to make it droop, in fact (Figs. 121 and 122).

Fig. 121.

Fig. 122.

Fig. 123.

Fig. 124.

Fig. 121.—Tube (a) with expanded evaporating surface (b) covered with animal or vegetable membrane directed downwards. The expanded portion corresponds to the roots of plants. When evaporation goes on at b, fluid presented at a is drawn through the tube in the direction of the arrow (the Author).

Fig. 122.—Similar tube with expanded portion directed upward. The expanded portion in this instance corresponds to the leaves of plants. When evaporation occurs at e, the fluid presented at d is drawn through the tube in the direction of the arrow f. Evaporation is to be regarded as a pulling force (the Author, 1872).

Fig. 123.—Tube (g) with expanded absorbing surface (h) covered with membrane and directed upwards to correspond with the leaves of a plant. When the thin fluid (rain or dew) is presented to the membrane, and to a thicker fluid contained in the tube, it passes by endosmose in a downward direction, as indicated by the arrow i. k, Vessel containing the thinner fluid (the Author).

Fig. 124.—Tube (l) with expanded absorbing surface (m) covered with membrane and directed downwards to correspond with the roots of a plant. When a thin fluid (sap from the earth) o, is presented to the membrane and to a thicker fluid contained in the tube, it passes by endosmose in an upward direction, as indicated by the arrow n. p, Vessel containing the thinner fluid. Endosmose is to be regarded as a pushing force (the Author, 1872).

Figs. 123 and 124.—Show how, in wet seasons, plants may be gorged with saps both from the leaves and from the roots, and how endosmose occurring in the leaves and roots tends to produce currents in opposite directions. The currents induced by endosmose are always the converse of those induced by evaporation, so that absorption and endosmose may be going on in the leaves, while evaporation is going on in the roots; the fluid in this case being pushed and drawn through the plant in a *downward* direction; or absorption and endosmose may be going on in the roots, and evaporation in the leaves, in which case the fluids are pushed and drawn through the plant in an *upward* direction (the Author, 1872).

In this case, the presence of heated air, or the condition of *dryness*, induce opposite currents. But respiring surfaces under certain conditions, say in wet or rainy seasons, may become absorbing surfaces. This is proved by the fact that a thin fluid will pass through an animal or vegetable membrane for which it has an affinity either from above or from below, according as the thin fluid is placed above or below the thicker fluid (Figs. 123 and 124).

From this it follows that evaporation, or the condition of *dryness*, draws or sucks the fluids out of the vessels and inter-vascular spaces, while the condition of *wetness* pushes or propels the fluids into them. Here we have a sucking or pulling force, and a pushing or propelling force; a *vis a fronte* and a *vis a tergo*; and I am disposed, as already indicated, to claim a like power for certain of the vessels and for the heart. But evaporation and absorption do not as a rule go on at the same surface at the same time. When a surface is absorbing it evaporates sparingly, and the converse. A free evaporation and a free absorption may, however, occur at the same time in different surfaces; and in such cases evaporation and absorption work together and not against each other (Fig. 117). Dryness and moisture in this way directly influence the circulation.

In the arrangement which I now advocate, evaporation or the withdrawal of fluids, and absorption or the addition of fluids, may take place at an infinite variety of points, and in such a manner as to favour rather than oppose the passage of the fluids in the capillary tubes and syphons. The syphons are set in operation by the presence of fluids, by capillary action, osmose, evaporation, and by vital and chemical changes occurring in growing parts.

If a superabundance of sap is presented to the roots, and an unusual amount of evaporation is going on in the leaves, the up current is increased in volume and intensity. If these conditions are reversed, the down current is proportionately augmented. The fluid contents of the plant oscillate between either extreme, and the up and down currents are equilibrated when all the forces which operate upon the plant are balanced,

A plant responds to external conditions as an Æolian harp responds to the wind.

The circulation is literally played upon by the elements. I might push the simile further, and apply the remark to ourselves; for the most exalted natures are ever the most susceptible—susceptible not only to psychical, but also to physical influences.

While engaged in describing the general circulation in plants, I volunteered an explanation of the intra-cellular circulation; the intra-cellular movements, as I endeavoured to point out, being in all probability due to evaporation, or to endosmose and exosmose occurring within or outside the cells, the rounded form of the cell converting what would under ordinary circumstances be merely opposite currents into rotatory ones (Figs. 111, 112, and 113). This led me to infer that certain movements (not necessarily those of gyration), occurring primarily within the cell, inaugurate the general circulation, but that when the general circulation is once established, it contributes to, and may actually produce, gyration in the cells themselves (Fig. 116 and Fig. 118). Finally, I endeavoured to show that all the forces engaged in the circulation in plants, whether vital or physical, act together to obtain a common result.

§ 104. Organic Forces a Modification of Inorganic Forces.

I have dwelt upon the subject of the circulation in plants at much greater length than I intended, or than was perhaps desirable under the circumstances; but it is one of extreme interest, since in it we have the germs of many of the arguments advanced to explain the circulation as it exists in man himself. Thus we are told that the tissues drink out of the blood and draw it onwards, supplying a *vis a fronte;* that secreting glands produce a similar effect; that the column of blood in the arteries is balanced by that in the veins; that the several compartments of the heart have a sucking and propelling action—in other words, that they pull as well as push; that evaporation assists in determining a flow of blood to the lungs, the movements of respiration assisting those of the circulation; that the play of the muscles urges the blood forward, much in the same way that the sap is occasionally urged forward in trees in virtue of their stems and branches swaying in the wind. In discoursing of the circulation in a plant or an animal, we are necessarily discoursing of motion as a whole, as it exists in the physical universe. In fact, we are compelled to regard the forces which operate in the inorganic world as essentially the same as those which operate in the organic; for in all vegetable and animal movements we have ultimately to deal with those of the molecules, cells, and tissues; nay, more, with the atoms or ultimate particles of matter composing them. The cells and particles of which an organism is composed may be operated upon singly and act individually; or they may be operated upon conjointly and act in masses. In the former case we have motion as a consequence of endosmose and exosmose, capillary and other attractions, vital and chemical, occurring in the ultimate molecules. In the latter case we have motion proceeding from a battery of force, such as that furnished by the several compartments of the heart; these, by their united complex movements, urging on the circulation to a great extent independently. But for the movements primarily occurring in the substance of the heart, the highly differentiated movements representing the diastole and systole of that organ could not take place. The primary molecular movements, if I may so phrase them, always precede those of greater magnitude. In the one we have the particular movement, in the other the general; but nature, with infinite wisdom, has so arranged that the general movement shall harmonise with the particular. Thus the heart may act in the circulation of an animal as a *vis a tergo*, and the demand for nutritious juices in the tissues as a *vis a fronte*. They may even act separately. The heart may push forward its blood into an artery occluded by a ligature, and the plant may draw on its juices when no heart exists. As all vegetables and animals may be resolved into inorganic atoms, so the physical and vital forces may be referred to a common source. It is thus that we reconcile the circulation in the plant and lower animals with that in the higher animals, and with certain movements which we know exist in the physical universe.

When we come to scan the dim borderland on which life and death struggle for pre-eminence, the most cautious observers and the gravest philosophers are often at fault. Indeed the human faculties only enable us to make very partial advances towards a solution of the great problems of life and motion. We are hedged in on all sides by boundaries which apparently we cannot override. If we advance beyond a certain point, a veil of greater or less density is interposed. This arises from the fact that even the greatest minds have a limited range, and that nature is as vast in her littleness as in her greatness. The telescope and the microscope have done much, but just in proportion to what has been done, it becomes apparent that so much the more remains to be done. Our most approved instruments, instead of simplifying matters, have actually complicated them. They have revealed wonder upon wonder, and convinced us that there are points which we must either take for granted or prove by analogy. This becomes very evident when we employ a microscope with a high magnifying power, and attempt to make out an ultimate structure; or, what is still more difficult, define the nature of certain movements

which take place under our eye, but which we cannot comprehend, as we are at a loss to know whether they are organic or inorganic. Under such circumstances the head becomes confused with thinking and the eye with watching, and all to no purpose. If, for example, we examine a salivary cell, we find apparently deep in its substance a great number of infinitely minute objects, each of which is evidently in motion. They are seen after a little careful focussing to quiver and vibrate, and even to rotate. These afford examples of the so-called Brownian movements, and are now regarded as physical in their nature. They provide the first glimmerings of visible motion. If we examine a vegetable or animal infusion after it has stood for a short time, we find a scum or pellicle on its surface. A considerable portion of this scum consists of a molecular mass in which no movement whatever can at first be detected. By and by, however, an aggregation of the molecules takes place, and when this aggregation occurs, there, of a certainty, movement makes its appearance. The movement is very indistinct, and it requires an experienced eye to detect it. As the infusion becomes older, the aggregation of molecules becomes more distinct, and the movements exhibited by them more marked. A careful observer will now perceive little dark points and rod-shaped bodies darting about in the field as if by magic. They do not change form, and apparently have no power of contracting and expanding; nevertheless they advance, recede, pause, advance again, and whirl about with a mad energy which is truly wonderful.

If the infusion be still older, long pointed bodies are found, which advance with a zig-zag or wavy serpentine motion, but still without any trace of contraction or expansion in any part of their substance. These constitute the now famous vibrios and bacteria, concerning which so much has been said lately. As to their mode of production and real nature, there is still a doubt in the scientific mind. All, or nearly all, are agreed that they are living things—a belief favoured by the fact that they increase and multiply. As to their movements there can be no doubt. Still more wonderful, in my opinion, are the movements of the amœba. This simplest organism consists of a mass of jelly, in which molecules of various sizes are embedded. This transparent creature, which remarkably resembles a white blood-corpuscle, and which is in the ordinary acceptation of the term structureless, has nevertheless the power of changing the shape of every part of its substance, and of advancing and retiring in whichever direction it pleases. The movements of this most singular creature are like those of water spilt upon the ground, or the spreading of a drop of fluid in blotting paper. The amœba causes its body, or a part thereof, to flow out in any direction it pleases. It literally pushes a certain part of its body outwards, and invades a certain portion of territory; the other parts of its body which are not advancing, remaining stationary. Contraction seems to take no part in this movement. When a part of the body is to be advanced, a transparent portion of it bulges, and into this the granules rush in a continuous stream; the knuckle or projection of the body advancing as the granules flow into it. There is no constriction, and nothing that can even suggest the idea of contraction. On the contrary, the parts of the body advanced are invariably wedge-shaped. There is change of form but no diminution of volume. The amœba has the power of changing form apart from contraction—a power which I believe is also possessed by the sarcous elements of muscles. I am indebted to my friend Dr. M'Kendrick for an opportunity of studying those movements under unusually favourable conditions, and direct attention to them because I am desirous of impressing upon the reader the necessity, when considering the circulation, of taking into account a large number of vital and a still greater number of physical forces, which all work together to produce it. The tissues have a circulation of their own apart from the heart and blood-vessels, and the presence of a heart, blood-vessels, or indeed of differentiated canals, is not necessary to certain forms of the circulation. Again, the heart, when it exists, impels the blood in virtue of its inherent movements, that is, the movements which occur in its sarcous elements or ultimate particles; these in turn being traceable to nutritive and other changes induced by the circulation itself. In fact, in the circulation, we have before us a very involved problem of vital, physical, and chemical reactions.

§ 105. Motion a Condition of Matter.

It will greatly facilitate our comprehension of the circulation if we bear in mind that motion is a condition of matter.[1] "Of absolute rest," as Grove eloquently puts it, "Nature gives us no evidence. All matter, as far as we can ascertain, is ever in movement, not merely in masses, as with the planetary spheres, but also molecularly, or throughout its most intimate structure." Grove, Matteucci, Mosotti, Plücker, Seebeck and others have worked at this subject, but especial thanks are due to the first-mentioned author for his masterly and exhaustive treatment of the subject. The gist of the following remarks is to be traced to him:—Force, like matter, cannot be annihilated; and where we have the one we have the other. Thus, matter and force are correlates in the strictest

[1] Many advanced thinkers are of opinion that there is but one force, and that all the others are modifications of it. Sir George Grove, in his work "On the Correlation of Physical Forces," says, "I believe that the same principles and mode of reasoning as have been adopted in this essay might be applied to the *organic* as well as the inorganic; and that muscular force, animal and vegetable heat, &c., might, and at some time will, be shown to have similar definite correlations."

sense of the word; the conception of the existence of the one involves the conception of the existence of the other: the quantity of matter, again, and the degree of force, involve conceptions of space and time. When motion ceases to be visible, that is, when moving masses strike against each other and apparently stand still, motion is re-developed in the shape of heat, which is invisible motion. In the steam-engine, for example, the piston and all its concomitant masses of matter are moved by the molecular dilatation of the vapour of the water by means of heat; the movement of the molecules being imperceptible. If homogeneous substances come together, heat alone is generated; but if homogeneous and heterogeneous substances come together, electricity is produced; and some have thought that, whereas the contents of vegetable cells are heterogeneous, and the saps presented to them are nearly if not quite homogeneous, electricity takes part in the circulation. Motion will directly produce heat; and electricity, being produced by it, will produce magnetism—a force which is always developed by electrical currents *at right angles* to the direction of those currents. If electricity be permitted to rank as one of the forces in the general—that is, the up-and-down—circulation in plants, magnetism would explain why there should be cross currents also. If we now take heat as our starting-point, we shall find that the other modes of force may be readily produced by it. The heat of spring, by creating a demand for sap in the tree, may be said to inaugurate the circulation. Heat produces a movement in distant parts, and bodies coming together from a distance produce heat; inorganic bodies act upon organic ones, and *vice versâ*. What is inorganic now may be organic very shortly. The chemistry of the inorganic and organic kingdoms is essentially the same. It is owing to this circumstance that a living body can appropriate and assimilate foreign matter and maintain its position in nature. It is by these means also it keeps itself in a condition of health. This principle of force, which pervades both the organic and inorganic kingdoms, shows how an organised being may live in contact with inorganic or dead matter; how the organic and inorganic may give to and take from each other—may, in fact, reciprocate with positive advantage to both.

§ 106. Circulation in Metals.

Most readers will be taken by surprise when I speak of a circulation in metals, but Seebeck has shown that when dissimilar metals are made to touch, or are soldered together and heated at the point of contact, a current of electricity flows through the metals, *having a definite direction*, according to the metals employed; which current continues as long as an *increasing* temperature is gradually pervading the metals, ceases when the temperature is *stationary*, and flows in a contrary direction with the decrement of temperature. The same words might almost be employed in describing the circulation in plants. In spring, when the temperature increases, there is a steady current of sap in an upward direction; in autumn, when the temperature decreases, the current is reversed; in summer, when the temperature may be regarded as stationary, the ascending and descending currents may be said to balance each other or equilibrate. Nor is this all. If a voltaic current be made to act upon electrodes of iron, the molecules of the iron are made to rotate very much in the same way that the cell contents rotate or gyrate in plants. From the foregoing it will be evident that heat, electricity, magnetism, chemical affinity, and motion are all correlative, or have a reciprocal dependence. Plants and animals are especially susceptible to the influence of light; and it has been supposed, not without reason, that matter of every description is altered by exposure to it. Until, therefore, the organic and inorganic kingdoms are drawn more closely together, both as regards their physical constitution and mode of action, many of the so-called vital forces must remain unexplained. A force can only originate as a transmitted force; it has no existence as a force *per se*.[1] Force may be regarded as *static* or *balanced*, and *dynamic* or *motive*. Static force in the vegetable and animal kingdoms represents rest, or a state of equilibrium in the parts. We have this peculiar condition when a flexor and extensor muscle prevent motion in a joint. When this equilibrium is disturbed, dynamic or motive force preponderates over the static or balanced force. When a part is in a state of equilibrium, it is also in a state of tonicity (the term tonicity as here employed meaning a condition of rest), and ready to act in whichever direction the force preponderates; and this explains why, in plants, the circulation is now upwards, now downwards, and how, at other times, it oscillates and becomes temporarily suspended.

CIRCULATION IN ANIMALS (*Invertebrata*)

§ 107. Symmetry of Form in the Organs of the Circulation and the Body generally.

A consideration of the circulation as it exists in animals, and an attentive examination of the subject, not only induce me to believe that there is a striking analogy between the circulation in plants and animals, but that in

[1] The term "force," although used in very different senses by different authors, in its limited sense may be defined as that which produces or resists motion. ("Correlation of Physical Forces," p. 14.)

animals devoid of pulsatile vessels and hearts, it is in some senses identical, and traceable to the operation of the same forces. The direction of the forces is determined by influences exerted without or within the plant or animal, or partly the one and partly the other. Uniformity of action implies symmetry of parts; and it appears to me that plants and animals are symmetrically constructed in order that the forces displayed by them may equilibrate or balance each other, and in order that plants and animals as a whole or parts of them may experience moments of repose; alternate activity and repose culminating in those marvellous rhythmic movements which for ages have been a puzzle to anatomists and physiologists. Alternating activity and repose imply a balancing power in the structures in which they are manifested, and hence the bi-lateral symmetry which everywhere obtains in animal organisms, and in organs themselves. I can instance no more beautiful example than the heart itself. In the ventricles of the mammalian heart, the muscular fibres are arranged in six symmetrical sets of spiral fibres (three external and three internal), and these are so wonderfully and exquisitely convoluted that each individual fibre has a counteracting or opposing fibre; each region being equilibrated by an opposing region; the whole forming a minutely reticulated structure, in which the fibres cross with mathematical precision at all conceivable angles, the fibres by their shortening and lengthening producing a motion which is, in some senses, unique in the animal economy. Similar remarks may be made regarding the bi-lateral nature of the stomach, bladder, and uterus, and indeed of all parts of the body. The flexors and extensor muscles, when in a state of equilibrium, are in the condition of rest, and when the flexor shortens the extensor lengthens, and *vice versâ*. The one movement implies the other. In like manner each compartment of the heart has the power of opening and closing. That the one part of the heart *opens* while the other *closes* spontaneously and independently and apart from stimulation, is proved by this, that all parts of the heart act, even when they are deprived of blood. When, moreover, the heart is acting slowly, the ventricle or ventricles (if there be two) open before the auricle or auricles, as the case may be, close. I have frequently seen this in the fish and frog. I employ the terms *lengthens* and *shortens* when speaking of long muscles, in preference to *relaxes* and *contracts*—contraction literally meaning a diminution of volume, no such diminution occurring in the movements of a muscle. This is proved by causing a muscle to contract in a graduated vessel containing water. The water, though disturbed, always remains at the same level. I have suggested the terms *opens* and *closes*, when speaking of hollow muscles, as involving no theory as to the manner in which a muscle acts. All muscular movements are the result of *a vital change of shape* in the sarcous elements of which muscles are composed, the volume of the sarcous elements always remaining exactly the same. Such change is not expressed by the terms contracts and relaxes. Contraction is usually regarded as a vital or *active* movement, relaxation being erroneously regarded as a mechanical or *passive* one.

§ 108. Respiration and Assimilation connected with the Circulation.

In order to have a just conception of the circulation as it exists in animals, it will be necessary to examine it in connection with the movements of respiration and nutrition, and the movements of the soft and hard parts generally.

There is a considerable proportion of the lower animals in which no trace of a circulation has yet been detected, the nutritious fluids in such cases being supposed to pass from the alimentary canal by interstitial transudation throughout the entire body, as the sap passes into the substance of cellular plants. One great obstacle to a proper understanding of the circulation in many of the lower forms of organic animal life is the difficulty experienced in determining whether the currents observed in inclosed spaces within their bodies belong to the circulation of their blood and nutrient juices, or are a means to a very different end, namely, respiration, locomotion, and other widely dissimilar functions. In sponges, which live and grow in water, this element passes in continuous currents through pores and canals in their substance. These currents enter at one point and issue at another, and are not, as Dr. Grant showed, due to the contraction of the canals. He suggested that they might possibly be due to the action of cilia, and Huxley and Bowerbank have succeeded in demonstrating the presence of those structures. It is only when cilia, blood-vessels, or hearts are present that the forces assume a visible form.

§ 109. Ciliary Currents.

Dr. Sharpey, in his admirable paper "On Cilia," shows that definite currents may be produced by ciliary movements. He instances two currents, which he found within the tentacula of the actinia; the one running from the base to the point of the tentaculum, the other in an opposite direction. He observed similar currents in the asterias and echinus; and those currents, he remarks, curiously enough, continue after the parts which

exhibit them are detached from the animal, from which it follows that they are beyond the reach of the will. The peculiarity of the currents referred to consists in this, that they run in opposite directions as in plants. In the polypi, medusæ, planaria, and some entozoa, where a circulation is absent or very obscure, the cæca of the alimentary canal is much branched, and evidently assists in carrying nutritious juices to all parts of the body. It thus performs in a great measure the functions of a circulatory apparatus, as well as of an alimentary canal. What fluids are not circulated by the cæca are circulated under such circumstances by a transudation or interstitial movement, as in plants. In several of the medusæ no distinct organ of circulation can be detected, the alimentary canal in such cases being of large size, and ramifying in every direction on the surface, or in the substance of the animal. Hitherto I have been dealing with the circulation as it exists in plants, and in the lower forms of animals, where neither contractile vessels nor hearts are present. When vessels are present, as in the cestum and beroe, Eschscholtz has shown that a large loop or ring of vessels surrounds the mouth, from which arteries and veins proceed ; branches passing to the fins, which at once serve for respiration and locomotion ; the fins in this respect resembling the growing wings of many insects. It is not quite ascertained whether in the beroe the circulating fluid, which is of a yellowish colour and contains globules, is actually blood. In the diplozoon (a small entozoon), Nordmann made out, with a high magnifying power, currents moving in opposite directions in two sets of vessels occurring on either side of both limbs of the animal. These vessels terminate posteriorly in a kind of sac, and, according to Nordmann and Ehrenberg, they neither contract nor dilate. We have now got distinct vessels in animals minus contractile power as in plants.

In the compound ascidiæ, as Lord Lister has shown, the different individuals of the branched animal are united by a polypiferous stem, and have a common circulation. Each individual is furnished with a heart consisting of a single cavity, which pulsates thirty or forty times per minute. In the common stem two distinct currents are traceable, these running in opposite directions (Fig. 118). One of the currents enters the ascidia by its peduncle, and goes direct to the heart. It proceeds thence to the gills and system generally, which having traversed, it leaves the animal by the peduncle at which it entered, and passes into the common stem, to circulate through another ascidian. The direction of the currents is reversed every two minutes or so ; and Lord Lister found that, if an ascidian was separated from the common stem, the separated individual can set up an independent circulation, consisting of two currents likewise running in opposite directions. The circulation in the ascidiæ is very remarkable, and closely resembles that in many plants. It occurs in non-contractile tubes, and in the absence of cilia. It is distinguished by an ascending and descending current, free to enter and leave the animal, as the sap is free to enter and leave the plant. The circulation, moreover, reverses and oscillates, and it may go on independently in an individual or in a community of individuals. Precisely the same remark may be made of the tree, for in this also the circulation oscillates, and if a portion of a tree, say a vine, be forced, it sets up a circulation of its own, while it at the same time maintains a certain relation with the other parts of the tree which are not forced (compare Fig. 89 with Fig. 118).

In the leech, sand-worm, and earth-worm, the circulation is, if possible, more tree-like. In these the blood (which is red in colour) moves slowly forward in the vessels situated on the dorsal surface of the animal, the direction of the current being reversed in the ventral vessels. If the leech, to which my remarks more especially apply, be placed in a vertical position, the currents of course correspond to the ascending and descending currents of plants. Between the dorsal and ventral vessels are numerous transverse vessels, which carry on a lateral or cross circulation, this too being analogous to what is found in plants (see Fig. 89, and compare with Fig. 125).

There are no distinct hearts in the leech, sand-worm, and earth-worm, the circulation being carried on mainly by the closing of the vessels at different points.

RHYTHMIC MOVEMENTS—Analogy between Involuntary and Voluntary Movements

If the vessels closed throughout their entire extent, very little if any movement would occur. If, again, the centre of a long vessel closed, the fluid would be driven away from the constricted point in opposite directions. To insure a circulation of the nutritious juices in a particular direction when valves are not present, the vessels must open and close in parts, in a certain order, in a given direction, and at stated intervals ; one part opening while another is closing, and *vice versâ*. This is what virtually takes place in the lashing of cilia. First one moves and then another, to form a progressive wave of movement ; this in its turn forming a progressive wave of fluid. It is this peculiar kind of movement that determines the wave of the pulse. The wave movement of cilia has been aptly compared by Dr. Sharpey to the undulating motion produced by the wind on a field of corn, and exactly resembles what I myself have seen in the living mammalian heart. The alternation of movements diametrically opposed

to each other, if they occur at regular intervals, constitutes the so-called rhythmic movements. These movements are witnessed in the blood-vessels, the heart, the intestines, the stomach, the bladder, and the uterus. They recur at very long intervals in the uterus, but the element of duration or time does not destroy the nature of the movement; the action of the heart is a rhythmic action, whether the organ beats 50 to the minute or 100.[1] It is the nature of the movement which settles its claim to be regarded as rhythmic or not. Hollow muscles display rhythmic movements when one part of their substance opens and another closes simultaneously; these movements alternating and repeating themselves at longer or shorter periods. Thus the stomach, bladder, rectum, and uterus close when their sphincters open; and their sphincters close when the viscera open. Minutes, hours, days, weeks, or months may elapse between the opening and closing of the parts of a hollow viscus, but when they do open and close, its movements are essentially rhythmic in character. Very similar remarks may be made regarding the voluntary muscles. The voluntary muscles, like the involuntary, are arranged in cycles, the closing of one half of the cycle being accompanied by the opening of the other; in other words, when the muscle constituting the one half of the cycle shortens, the other elongates. In the involuntary muscles the cycle closes in all its diameters, to expel fluid or other contents. In the voluntary muscles the diameter of the circle remains the same, the object being to cause the jointed bones placed within the cycle to move in specific directions. The motion of the voluntary and involuntary muscles is essentially wave-like in character—that is, it spreads from certain centres, according to a fixed order, and in given directions. Thus the ventricular portion of the heart closes towards the pulmonary artery and aorta; the stomach towards the pyloric valve; the rectum towards the sphincters ani; the bladder towards the urethra; and the uterus towards the os. It is the same in the movements of the extremities; the centripetal or converging muscular wave on one side of the bones to be moved being accompanied by a corresponding centrifugal or diverging wave on the other side; the bones by this means being moved to a hair's-breadth. The centripetal or converging, and the centrifugal or diverging waves of force are correlated. The same holds true of the different parts of the body of the serpent when creeping; of the body of the fish when swimming; of the wing of the bird when flying; and of our own extremities when walking. In all these cases, the moving parts are thrown into curves or waves.[2] It could not be otherwise. If fluids are to be propelled in certain directions, forces which act in definite directions must be provided. This also holds true of locomotion, however performed; whether by a living undifferentiated mass, that is, a mass devoid of nerve, muscle, bone, &c.; or by an animal in which all these are present. It may seem out of place to refer to the voluntary muscular movements here, seeing I am called upon, strictly speaking, only to deal with the involuntary. It, however, appears to me, that the two must be studied together: that, in fact, the compound involuntary muscles, such as the heart, stomach, bladder, and uterus, give the cue to the muscular arrangements in the extremities and bodies of animals generally.

Hitherto it has been the almost invariable custom in teaching anatomy, and such parts of physiology as pertain to animal movements, to place much emphasis upon the configuration of the bony skeleton as a whole, and especially the conformation of its several articular surfaces. This is very natural, as the osseous system stands the wear and tear of time, while all around it is in a great measure perishable. It is the link which binds extinct forms to living ones, and we naturally venerate what is enduring. It is no marvel that Oken, Goethe, Owen, and others, should have attempted such splendid generalisations with regard to the osseous system—should have proved with such cogency of argument that the head is composed of expanded vertebræ. The bony skeleton is a miracle of design very wonderful and very beautiful in its way. But when all has been said, the fact remains that the skeleton, when it exists, forms only an adjunct of locomotion and motion generally. All the really important movements of an animal occur in the soft parts. The osseous system is therefore to be regarded as secondary in importance to the muscular, of which it may be considered a differentiation. Instead of regarding the muscles as adapted to the bones, the bones ought to be regarded as adapted to the muscles. Bones have no power either of originating or perpetuating motion. This begins and terminates in the muscles and soft parts. Nor must it be overlooked that bone makes its appearance comparatively late in the scale of being; that innumerable creatures exist, in which no trace either of an external or an internal skeleton is to be found; that these creatures move freely about, digest, circulate their nutritious juices and blood when present, multiply, and perform all the functions incident to life.

While the skeleton is to be found in only a certain proportion of the animals existing on our globe, the soft

[1] The frequency of the heart's action varies greatly in different animals. According to Burdach ("Physiologie," vol. vi. pp. 289–90), the number of pulsations per minute in the shark is 7; in the mussel, 15; in the carp, 20; in the eel, 24; in the snail, 34; in the horse, 36; in the caterpillar, 36; in the bullock, 38; in the ass, 50; in the crayfish, 50; in the butterfly, 60; in the goat, 74; in the sheep, 75; in the hedgehog, 75; in the frog, 77; in the marmot, locust, and ape, 90; in the dormouse, 90; in the cat and duck, 20 and 21; in the rabbit and *Monoculus castor*, 120; in the pigeon, 136; in the guinea-pig, hen, and *Bremus terrestris*, 140; and in the heron and *Monoculus pulex*, 220.

[2] That an intimate relation exists between the organs of locomotion and the structures which carry on the circulation and the digestion in the higher animals, is rendered exceedingly probable by the fact, that the cilia of the infusoria enable those creatures to move from place to place, and produce the currents which enable them to seize their food and respire.

parts are to be met with in all; and this appears to me an all-sufficient reason for attaching great importance to the movements of soft parts; to protoplasm, to moving jelly masses, to involuntary muscles such as the œsophagus, stomach, intestine, bladder, uterus, heart, and blood-vessels. It may appear far-fetched to state that the voluntary muscle is a differentiation and further development of the involuntary; that the movements of the œsophagus, stomach, and intestines prefigure those of the blood-vessels; that the movements of the blood-vessels prefigure those of the heart; that the movements of the heart prefigure those of the chest and abdomen; and that the movements of the chest and abdomen prefigure those of the extremities: but such, I believe, is actually the case.[1] Indeed I hope to be able to show in the present work, that if I eliminate the element of bone from the chest and the extremities, the direction of the muscular fibres of those parts will correspond exactly with the direction of the muscular fibres of the ventricles of the mammal; nay, more, that even the bones of the several regions, especially of the extremities, are twisted upon themselves in the form of a double spiral, and in a manner resembling that in which the fibres of the heart are convoluted. This is especially perceptible if the internal fibres of the left ventricle of the heart be compared with the bones of the bird's wing; or the bones of the anterior extremity of the elephant; or the bones of the extremities of any quadruped.

I hope further to be able to prove that the heart within the thorax is a heart working within a greater heart—the thorax itself; the two having a common function, namely, to bring the air and the blood face to face, so as to enable them to reciprocate with the utmost facility and in the most direct way possible.[2] I might make similar observations regarding the stomach, intestine, bladder, and uterus. These are hollow muscles[3] situated within the abdomen, a still greater hollow muscle; and when any of them acts, the abdominal muscles take part in the movement. The hollow muscles and abdomen may, however, act separately, just in the same way that the heart may act when cut out of the thorax. The several points here referred to are illustrated at Figs. 180 to 185 inclusive, pp. 532 and 533. I have to apologise for these digressions, but the object of my treating the subject of the circulation comparatively is to bring out contrasts, and to eliminate, if possible, from a mass of detail, some principle or principles.

§ 110. Circulation in the Leech contrasted with that in Plants.

The circulation in the leech affords a good illustration of what may be done by rhythmic movements acting in a given direction; the rhythmic movements of the blood-vessels sufficing for carrying on the circulation within the body of the leech; and, what is not a little curious, the rhythmic movements of the œsophagus of the leech causing the blood of another animal to circulate within its œsophagus and alimentary canal when it feeds.[4] According to J. Müller, for a certain number of pulsations, the middle and the lateral vessel of one side contract together, and propel the blood into the lateral vessel on the other side; and then the order is reversed, and the middle vessel acts along with the lateral vessel of the other side, so that *one lateral vessel is always dilated, while the median and opposite lateral ones are contracted*, and *vice versâ*.

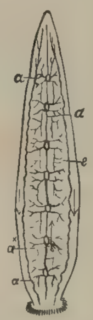


FIG. 125.—*a*, *a*, Principal and most highly contractile vessels of leech. *e*, cross vessels.

Some anatomists believe that in the leech there is a simple oscillation of the blood from side to side, or across the animal; others that there is, in addition, a general progressive movement of the blood *forwards* in the upper vessel, and *backwards* in the lower one (*vide* arrows). The latter view is most probably the correct one, for when a vertical and horizontal system of vessels are united to each other by innumerable capillary loops, a certain proportion of the blood necessarily flows round or gyrates. Indeed it would appear that the blood flows in a circle round the margin of the animal, much in the same way that the granular contents of the cell in many plants gyrate; that when the upper vessel closes, it forces the blood *forwards* and laterally; the lower vessel, when it closes, forcing the blood *backwards* and laterally. There is nothing contradictory in this supposition. The principal forces act on opposite sides of a circle; the minor forces acting transversely. If the vessel on one

[1] The extremities are a differentiation of the trunk. They are not necessary to existence; they may be lopped off and the trunk live as before.

[2] As the circulatory apparatus in the embryo becomes developed, it is necessary that a respiratory apparatus be provided for depurating the blood. This depurating structure is termed the *allantois*. It sprouts from the anterior and lower part of the wall of the belly of the embryo, at first as a little mass of cells, which soon exhibits a cavity, so that a vesicle is formed which looks like a diverticulum from the lower part of the digestive cavity. This vesicle in birds has been shown by Vulpian (*Journ. de la Physiologie*, tome i. p. 619 et seq.) to be possessed of *a distinct contractile power*, and soon becomes so large as to extend itself around the yolk-sac, intervening between it and the membrane of the shell, and coming through the latter *into relation with the external air*: but in the embryo of mammalia, the allantois, being early superseded by another provision for the aëration of the blood, seldom attains any considerable dimensions. (Carpenter's "Human Physiology," Lond. 1864, pp. 800, 801.)

[3] The hollow muscles are adapted for transmitting air, fluids, or solids. Usually they only transmit one of these. The intestine transmits all three.

[4] When speaking of the teeth of the common leech, Mr. Dallas remarks, that immediately the teeth, three in number, have sawed through the skin, they are retracted and the blood pumped from the wound by the alternate dilatation and contraction of the muscular œsophagus. ("Natural History of the Animal Kingdom," by W. S. Dallas, Esq., F.L.S., p. 95.)

side of the animal closed throughout its entire length, it would certainly force the blood through the lateral or transverse branches into the vessel on the opposite side; this again, when it closed, reversing the movement. In this arrangement the circulating fluid would receive a check, that is, it would have a halt or dead point between each oscillation. There would be this further difficulty: the vessel would close at once throughout its entire length, instead of consecutively and in parts. By adopting the view now suggested, the blood will flow in one continuous round without halt or dead point, and be compelled to do so by a kind of vermicular movement, that is, by a simultaneous opening and closing of the different parts of the vessel, akin to swallowing; the wave-like movement travelling in one direction, the cause and the effect being equally intelligible. The circulation in the leech resembles that in the plant in this, that it consists of an ascending, descending, and transverse current (compare Fig. 89 with Fig. 125). There are, however, in addition, well-defined blood-vessels which are endowed with the power of opening and closing for a specific purpose.

The presence of vessels, as has been already shown, is not necessary to the circulation. In young and abnormal tissues, even in animals, the blood tunnels out channels for itself in determinate directions, and around these channels blood-vessels are ultimately formed.[1] The direction of the current of the blood and nutritious juices is determined by processes of growth, by capillarity, osmose, and evaporation, occurring in the animal. It is, however, quite natural that when the vascular system becomes differentiated the blood-vessels should be laid down in the exact position of the original currents, the existence of which is as necessary to their own formation as that of the tissues generally.

§ 111. How the Circulation connects the Organic and Inorganic Kingdoms.

In plants and in the lower animals, the distinguishing feature of the currents constituting the circulation is that they proceed in the direction of the length of the plant or animal, and transversely—the vertical and horizontal currents running at right angles to each other. The circulation in plants is essentially an interrupted or disjointed circulation. It occurs within capillary or other syphon tubes or spaces, the syphons being directed alternately towards the leaves and the roots, in which direction the extremities of the syphons are united by vegetable membranes, which prevent the ingress of air, and preserve the integrity of the syphon action, while they at the same time facilitate absorption, evaporation, and osmose. The saps of a plant ascend, descend, advance, and retire, in a series of waves. They rarely gyrate, unless when two systems of alternating syphons unite to form circular spaces, in which case the circulation resembles that within cells or the bodies of animals. Plants grow into the earth and air, or into the water and air. The earth and water operate upon their circulation at one end—the air and its vapours at the other. Plants for the most part are fixed. It is otherwise as a rule with animals. These move freely about on the land, or in the water or air. The circulation in animals is, with few exceptions, a closed or complete circulation, that is, the juices flow in a continuous circle. This is necessary because the forces of the circulation in animals are more strictly speaking a part of themselves.

§ 112. The Digestion and the Circulation.

The leech, for example, has no roots to dig into the ground, or leaves to spread out in the sunshine, for the purpose of absorbing and giving off moisture. It, however, does this indirectly by its mucous linings and skin, by its blood-vessels and by its tissues generally, all of which are capable of absorbing and giving off moisture.[2] It takes in its food and fluids by the mouth; these being made to traverse a distinct alimentary canal. The circulation is, so to speak, without, beyond, or cut off from the nutritious juices supplied by the mouth; these being conveyed to the blood indirectly, and in such a way as would not suffice for carrying on the circulation. In the plant the nutritious juices absorbed by the roots at once suffice for nourishment and for carrying on the circulation. The same holds true of animals very low down in the scale. In the higher animals, however, the food and drink

[1] The vessels are at first solid cylinders made up of formative cells cohering together. By liquefaction of their substance in the interior, these cylinders become tubes, and their central cells thus set free are the primitive blood-corpuscles. ("Quain's Anatomy," 7th edition, clxxx.) In the formation of the Haversian canals in bone, the vessels first pour out the animal matrix, and then deposit in it the bone earth; thus by degrees they come to be surrounded by their own work. (Holden's "Human Osteology," p. 32.)

"We have the fact, that in each plant, and in every new part of each plant, *the formation of sap-canals precedes the formation of wood;* that the deposit of woody matter, when it begins, takes place around the sap-canals, and afterwards around the new sap-canals successively developed; that the formation of wood around the sap-canals takes place when the coats of the canals are demonstrably permeable, and that the amount of wood-formation is proportionate to the permeability. ("Principles of Biology," by Herbert Spencer, vol. ii. p. 564.)

[2] Boerhaave says in one place, An animal is a plant which has its roots (internally) in the stomach. Perhaps some other might with equal propriety play upon this idea and say, A plant is an animal which has its stomach (externally) in its roots. ("Kant's Lesser Metaphysical Writings." Leipzig, 1838, p. 62.)

swallowed contribute only indirectly to carrying on the circulation, this being effected by a distinct apparatus specially provided. Indeed between the food as received into the stomach, and the blood as elaborated for nutrition, there is a considerable gap—the gap being traversed by a distinct set of vessels, the so-called lacteals or chyliferous ducts. Through these, and through the capillary blood-vessels, the nutritious portions of the food reach the blood. Between the nutrition as carried on in the plant and animal there are what may be regarded as intermediate systems. Thus in the flustra, a form of polype, the particles taken in by the mouth as food rotate within the stomach and rectum, very much in the same way that the contents of certain plant-cells do. Here the food of the animal circulates in a manner analogous to that in which the pabulum of the plant, or the white and red corpuscles of the blood of the mammal, circulate. This shows how very intimately the functions of the circulation and the digestion are related to each other.[1] Indeed the object and aim of the circulation in every case is to provide nourishment for distant parts, and to expose the circulating fluids freely to the air. The circulation connects the plant with the earth and the air. It enables the plant to give to and receive from both, in fact fixes its place in nature. The animate and inanimate kingdoms are by the aid of the circulation enabled to reciprocate. What is said of the plant may also be said of the animal. It is the circulation which more especially connects the animal with the outer world. The pabulum taken in by the mouth of the animal very soon finds its way to the blood, and the circulation insures that the blood duly reciprocates with the air. In plants the air and circulating fluids are in many cases mixed, and in insects the whole animal is traversed by innumerable air-tubes, which convey air to every part of the body. It is in this way that the peristaltic movements of the stomach and intestines are related to the rhythmic movements of the heart, blood-vessels, and lungs ; these, in turn, bearing a certain relation to the voluntary muscles. If the voluntary muscles are set violently in motion, as in running or wrestling, these, as is well known, quicken the movements of both lungs and heart. Looking at the circulation in its entirety, we are compelled to take in a wide range of phenomena and forces, the relations of which are as yet imperfectly understood. A more extensive acquaintance with the subject will, I have no doubt, bring out the interesting fact, that the phenomena and forces are all correlated to each other. It is impossible to speak of the circulation apart from the respiration and the digestion ; and these, in the higher animals, are linked by a silver chain to the nervous system, which, in its turn, reacts upon all the three.

§ 113. Cilia, their Form and Function.

While it is impossible to fix upon any one force which may be said to carry on the circulation in plants, there are forces at work in the lower animals which would be quite equal to the task. I speak of the forces residing in cilia, which may be classed as visible forces. Cilia are conical-shaped, hair-like processes, semi-transparent, elastic, and apparently homogeneous. In some cases the cilia are flattened out so as to resemble the blade of an oar, the blade in some instances being digitated and resembling the feathers of the wing of a bird. Under these circumstances they are usually employed as organs of locomotion. In the infusoria the cilia are apparently under the influence of the will. There are, however, numerous cases where they are not, and where they vibrate for protracted periods after having been removed from the body. They occur in incalculable numbers, and are in some instances infinitely minute. They are found on the external and internal surfaces of the lower animals ; and on the mucous lining of the nostrils, lungs, Eustachian, Fallopian, and other tubes of the higher. In some cases they are arranged in straight rows, and in others they form circles or spiral lines. Some observers are of opinion that they contain muscular fibres or what are equivalent thereto, in their interior ; and Ehrenberg showed that they had muscles attached to their roots. Dr. Grant, as already indicated, thought that they were tubular, their movements being due to the absence or presence of water in their interior. They are especially deserving of attention as foreshadowing an infinite variety of movements in the animal economy. They lash about with a vibratile or reciprocating rhythmical motion, the one after the other, in such a manner as to produce a waved surface, resembling that produced by wind upon water, or, as Dr. Sharpey well put it, wind among corn. Their movements, while they last, are regular and definitely co-ordinated ; that is, they move in certain directions with various degrees of speed, and produce currents which flow in definite directions. They have thus the power of propelling fluids in given directions, over any surface on which they are situated. One of the most remarkable motions, essentially ciliary in character, is witnessed in the spermatozoa of the common earth-worm (*Lumbricus agricola*). Immediately the spermatozoa are extruded from the testes, everything in their proximity becomes ciliated by them ; one end

[1] "The first rudiment of the *heart*, which is the earliest of the permanent organs of the embryo that comes into functional activity, consists of an aggregation of cells, forming a thickening of the fibrous coat of the *anterior portion of the intestinal canal* ; the innermost cells of which, becoming detached, float in the newly-formed cavity as the first blood-corpuscles, whilst the outer remain to constitute its walls. For a long time after it has distinctly commenced pulsating, and is obviously exerting a contractile force, its walls obviously retain the cellular character, and only become muscular by a progressive histological transformation." ("Carpenter's Human Physiology," 1864, p. 799.)

becoming fixed, the other vibrating free. They thus actually establish ciliary currents on inanimate surfaces; and if the substance to which they attach themselves is not too large, they drag it about with an undulating motion, and sometimes cause it to gyrate. This is precisely the kind of force which would suffice for carrying on the circulation, in the absence of a heart and pulsatile vessels; but cilia have not hitherto been found either in the vascular tissues of plants or animals, or on the globules either of the blood or lymph. The function of cilia is very varied. In certain cases they produce currents outside the animal; their presence on the interior of the stomach causing its contents to rotate or gyrate. They serve as organs of locomotion, and some are of opinion that they act as lungs and organs of sense. They are, therefore, endowed with this very remarkable property, that they can produce currents in a given direction on any particular surface; or they can cause the whole animal to move in a line to any given point. They also assist in the processes of digestion and respiration. Here is a multiplicity of function, and it is by regarding such structures that the movements of the blood-vessels and heart are, in some measure, identified with those of the intestine, stomach, bladder, and uterus; and the movements of the intestine, stomach, bladder, and uterus with those of the voluntary muscles.

Cilia are endowed with wonderful vital powers; they live after being separated from the body, and until the parts on which they are found are on the verge of putrefaction. This shows that they can operate independently of the will. The heart also acts independently of the will, and after being removed from the body, so that both as regards their tenacity of life, their rhythmic movements, and their involuntary actions, the cilia and heart have many points in common.

§ 114. Undefined Forces of the Circulation—Slowing and Quickening of the Circulation, &c.

The inference I draw from the foregoing is this: If in nature there are vital forces which can act independently of the will, and produce continuous or interrupted currents in definite directions, it is not difficult to understand that a plant or animal, or *parts thereof*, may exert vital powers in an equally precise and definite manner although unseen. The life of a plant or animal represents the aggregate movements of its structural elements; and although we cannot trace with the naked eye or microscope the grouping and combined action of its various molecules, or, what is the same thing, the differentiation of its forces, we are, I think, bound to conclude that the life has much to do with the regulation and distribution of those forces in living organisms. The seed has those forces pent up within itself, and when it is placed in proper conditions they manifest themselves. If, however, the seed is dead, those conditions do not affect it. It is very probable that when the seed is dead its structure is so changed that the physical forces which would come into play in a living seed are inoperative. If the tissues are composed originally of similar elements variously combined, it is difficult to resist the conclusion that the life has much to do with the production of each. What other than a vital chemistry could transform a mass of protoplasm into the aqueous humour of the eye, the ivory of the tusks and teeth, the hard, resisting bone, and the actively moving muscle? It was long before the presence of cilia was detected in parts where we now know they exist, and it is quite possible that auxiliary forces, infinitely minute but spread over large surfaces, may assist the heart and blood-vessels in carrying on the circulation. There is no absolute necessity for supposing the existence of such forces; as osmose, capillary attraction, absorption, evaporation, chemical affinity, &c., aided by pulsating hearts and blood-vessels, are of themselves equal to the task. In a living organism, however, where every part helps every other part, and where all is motion, it is scarcely reasonable to suppose that the *onus* of pushing or pulling forward a mass of fluid would be delegated entirely either to the heart or the blood-vessels. In plants, as has been explained, fluids can circulate without either the one or the other; and a portion of skin may be taken from one animal and placed upon an open sore in another, and made to grow; its connections with the heart and blood-vessels of the animal from which it was removed being completely destroyed. These facts, coupled with the circumstance that sap is determined to the growing parts of plants and animals, form a strong presumptive proof that in the latter, as in the former, a great variety of hidden or invisible forces are at work. This argument is not demolished by saying that if the heart is removed in an animal the general circulation ceases. It may happen that while the invisible forces are inadequate of themselves to carry on the circulation in an animal they may nevertheless afford invaluable assistance. In the cold-blooded animals the capillaries propel the blood for some time after the heart has been removed. The motion proceeds from the smaller to the larger vessels alike in veins and arteries. Haller, who especially investigated this subject, thought that this phenomenon could not be due to the contraction of the large vessels, to capillarity, nor to gravitation. He attributed it to some unknown power residing in the solid tissues which attracted the blood, and also to the action of the globules of the blood upon each other. It may in reality be due to a reverse endosmotic action; the blood, during the process of cooling, coagulating and becoming thicker than the serum outside the vessels. What originally passed out of the capillaries by endosmose may in part return to

them, the return being favoured by the closing of the capillaries and a diminished evaporation due to a loss of animal heat. Dr. Alison believed that the capillaries of animals exerted a peculiar propulsive power apart from contractility, and that the globules of the blood were possessed of the power of spontaneous motion. His hypothesis will be regarded by some as extravagant, but there is nothing ridiculous in it. The ova of fixed plants, as we have seen, leave the parent and lead an itinerant life, until they find a suitable habitat; the contents of cells gyrate; and cilia placed on certain surfaces produce currents in definite directions.

On watching the circulation in the mesentery of the frog some time ago, with my friend, Dr. Wyllie, I found it difficult to believe that the white corpuscles, while they floated in the blood plasma, were not endowed with a certain amount of independent movement. They loitered along the margins of the capillaries, now stopping here, now there, now advancing a little, and now halting resolutely: attaching themselves to the inner surface of the vessels, they forced their way in an outward direction and produced an external bulging, after which, changing their shape, they pushed themselves right through the capillary walls. Once outside the vessels, they reassumed their original form for a brief space, after which they gradually merged into the adjacent tissues, and became undistinguishable from them. The growth of the individual may, in this sense, be regarded as identical with its power of circulation: the one is correlated to the other. The organism lives because it has the power of circulating its nutritious juices. There are many facts which strengthen the hypothesis that the circulation of the blood within the capillaries is not entirely due to the action of the heart. The circulation of the blood may continue in the capillaries after the heart has ceased to act; or it may cease in parts, the heart acting vigorously the while. The flow of blood in the capillaries is not regular, which it would be if entirely dependent on the action of the heart. In some instances the circulation in certain of the capillaries within a given area is quickened, while in others within the same area it is slowed, and the direction of the current reversed. In cold-blooded animals the circulation within the capillaries goes on after the heart is excised. The arterial system, after most kinds of natural death, is found emptied of blood. In death by yellow fever, the external veins often become so distended, that on puncture the blood gushes forth as from arteries. Secretions depending upon the circulation within the capillaries go on after the heart has ceased to beat. In the early embryo the blood moves in the vascular area before it is subjected to the influence of the heart—the movement being *towards* instead of *from* the centre. The heart in some cases is absent during the whole of embryonic life—the organs being nevertheless well developed, which of course implies a capillary circulation. The circulation in the capillaries may be slowed or stopped by the local application of cold, and by local death or gangrene, which shows plainly enough that there is, as Sir James Paget cautiously puts it, "some mutual relation between the blood and its vessels, or the parts around them, which, being natural, permits the most easy transit of the blood, but, being disturbed, increases the hindrance to its passage." Professor Draper [1] thought that "if two fluids communicate with one another in a capillary tube, or in a porous or parenchymatous structure, and have for that tube or structure different chemical affinities, movement will ensue; that liquid which has the most energetic affinity will move with the greatest velocity, and may even drive the other liquid before it." The occult forces, if I may so call them, while they are not equal to carrying on the circulation by themselves, exert, I believe, sufficient power to relieve the heart and blood-vessels from excessive strain. It is, moreover, more natural for the tissues to drink leisurely, and according to desire, than to have blood unceremoniously thrust upon them by a violent *vis a tergo*. Where the blood has to travel long distances before it is utilised, a perfect system of blood-vessels and a heart are necessary for transmitting it to the scene of its labours. Arrived there, another set of forces comes into play. This is in part proved by the absence of the pulse in the capillaries. I may be here met by the statement that the force of a common injecting syringe can cause a fluid to pass through the arteries and capillaries so as to return by the veins. I have had considerable experience in artificial injections, and have invariably found that, unless extreme care is exercised, the capillaries are ruptured in the process. Nor is this due to coarse particles in the injection blocking up the capillaries, for the same pernicious effects follow when water is employed. It is the force that does the mischief, and this is another reason for believing that the circulation within the capillaries differs materially from that in the main arteries and veins. It could not be expected that the delicate capillary vessels, with their thin transparent walls, could resist without injury the same pressure brought to bear upon the aorta; nor are they called upon to do so, the pressure being diminished in proportion to the distance from the heart and the increase of area in the capillaries, as compared with that in the arteries. That the force exerted by the heart is modified as it is transmitted is abundantly proved by the greater thinness of the walls of the great veins, as compared with the great arteries. The slowing of the circulation in the arteries in the direction of the capillaries, and the quickening thereof in the veins in the direction of the heart, render it exceedingly probable that the ventricle, or ventricles, exert a propelling power, and that the auricle, or auricles, exert a sucking power. This is what virtually happens in the more simple forms of the circulation, when one surface absorbs and another respires; fluids entering the tissues

[1] "Treatise on the Forces which produce the Organisation of Plants," pp. 22–41.

by endosmose (which may be regarded as a pushing force), passing through them and escaping by the aid of evaporation (which may be regarded as a pulling force). The sucking or pulling power, and the pushing or propelling power, there is reason to believe, are possessed by each compartment of the heart—a circumstance due to the fact that the opening and closing of the different parts of the heart are equally vital acts. (They are vital in the same sense that the opening and closing of the medusa, and the vacuoles of such plants as the *Volvox globator*, *Gonium pectorale*, and *Chlamydomonas*, are vital.) Thus the auricle and ventricle, when they close, *propel* or *push* the blood; whereas, when they open, they *draw* or *suck* it. As the auricle closes when the ventricle opens, and *vice versâ*, it follows that when the ventricle is pushing, the auricle is pulling; the auricle pushing when the ventricle is pulling. The two forces, in fact, act together, the object being to cause the blood to flow in a circle. That each compartment of the heart—in other words, each pulsating cavity—has the power of gently sucking in the blood and forcibly ejecting it, seems proved by analogy. If a caoutchouc oval-shaped cylinder furnished with two apertures be compressed by the hand, to exclude the air, and immersed in water, it fills itself when it expands. The water can be extruded by the pressure of the hand, and the operation repeated *ad libitum*. If the apertures of the cylinder have fitted to them two tubes, one of which is supplied with a ball-valve as in some forms of enema syringe, water may be pumped out of a basin in a more or less continuous stream as by the heart, by immersing that end of the apparatus containing the valve, and applying an interrupted pressure to the cylinder, by alternately closing and opening the hand in which the cylinder is retained. When the cylinder is forcibly closed, it ejects the water; and when it spontaneously opens, it slowly draws it in. Precisely the same thing occurs in the heart of the lobster; the heart in this crustacean consisting of a single muscular sac, which gives off and receives several vessels (Fig. 129, *h*, p. 471). This reasoning is not vitiated by the fact that the vessels proceeding to and from the heart are flexible, for I have ascertained by experiment that the vessels may be as thin as tissue paper and not collapse when suction is applied to them, provided always they be full, or moderately full, of blood—blood, like other fluids, being nearly incompressible. If, for example, a piece of gut having a syringe attached to it at either end be immersed, and the gut and one syringe be moderately filled with water, I find that the water in the full syringe can be made to pass to the empty syringe, without in the slightest altering the calibre of the gut. This follows, because the contents of the gut remain always exactly the same. The transference is effected by one operator pushing down the piston of the full syringe, while another draws up the piston of the empty syringe. It is in this way that the vessels are always kept moderately full of blood, and that one compartment of the heart always closes and pushes at the same instant that another compartment opens and pulls. The blood ejected from the one compartment is received by the other, the vessels being always full; one compartment of a single heart (heart consisting of an auricle and ventricle), and two compartments of a double heart (heart consisting of two auricles and two ventricles), being always empty. From this it appears that two pulsating cavities, one of which opens when the other closes, are capable of carrying on the circulation in the absence of elasticity in the vessels. Nor will this occasion surprise. No substance is perfectly elastic; so that if much power was stored up in the vessels by the heart, a considerable proportion of it would be sacrificed. Such vessels as take an active part in the circulation open and close in parts rhythmically, and produce a kind of swallowing movement; this movement being due less to elasticity than vitality in the parts. The elasticity of the vessels is principally of use in causing the blood to flow in a continuous stream, the elasticity acting when the ventricles have ceased to act (that is, between the pulsations) in such a manner as definitely to co-ordinate the ventricular movements. Elasticity is also useful in keeping the vessels open, in permitting them to assume various shapes and positions, and in yielding to and correcting local congestions. The blood is most economically circulated by an apparatus which opens and closes spontaneously in parts; this arrangement reducing friction and conserving energy. Such an apparatus operates upon the blood and not upon itself. It can operate with or in the absence of elasticity, and performs work in whichever direction it moves. The object of the circulatory apparatus is to convey blood to and from the capillaries where the tissues are fed, and this can be done most conveniently by an apparatus which propels fluid in a circle, one half of the apparatus propelling or pushing the fluid round one half of the circle, the fluid being gradually slowed in its course; while it sucks or draws it round the other half, the fluid being gradually quickened in its course. By this arrangement no time is lost, the blood being slowed in order to afford the tissues an oppor-

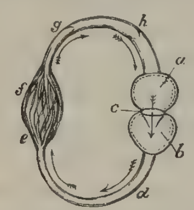


FIG. 126.—Diagram representing how the heart pushes and pulls the blood, and how the circulation is slowed and quickened. *a*, Auricle; *b*, ventricle (pulsating cavities), of exactly the same size; *c*, auriculo-ventricular orifice guarded by a mitral valve; *d*, artery; *e, f*, capillaries; *g, h*, vein. The ventricle (*b*) propels or pushes the blood towards the capillaries (*e, f*) when it closes; the auricle (*a*) sucks or draws it from them when it opens. The auricle always opens when the ventricle closes, and *vice versâ* (one compartment of the heart being always empty when the other is full). The blood is by this means forced in a circle (*vide* arrows). It is slowed in the direction *b, d, e*, and quickened in the direction *f, g, h, a*. The valves *c, g, h*, insure that the blood will always flow in the same direction (the Author, 1872).

tunity of taking from and giving to it, and quickened when these interchanges are not necessary. The blood is slowed as it proceeds from the heart, by the breaking up of the arteries into innumerable branches, and from a marked increase in the capillary area; the friction experienced by the blood *in transitu* being correspondingly increased. It is quickened as it proceeds towards the heart by the veins converging, and from a marked diminution in the venous area; the friction experienced by the circulating fluid being correspondingly diminished. (These points are shown in Fig. 126, p. 468.)

§ 115. Circulation in the Star-fish.

In the star-fish the intestinal vascular system consists of loops, from which arteries and veins are given off; these being connected with a dilated pulsatile canal, which may be regarded as a rudimentary heart. Similar remarks are to be made of the holothuria, so that we have at length arrived at what may be regarded as a visible force, namely, a pulsating vessel. It is a remarkable circumstance that in the mammal those veins which are not furnished with valves are largely supplied with non-striated muscular fibres, which run in two directions, namely, across and in the direction of the length of the vessel. This holds true of the inferior vena cava, the renal, azygos, and external iliac veins, and of all the large trunks of the portal venous system, and of the trunks of the hepatic veins.[1] These vessels have therefore the power, within certain limits, of opening and closing, and of forcing on the blood independently of valves. Valves are consequently accessory structures and adjuvants to the heart in the higher animals. The same is to be said of the nerves found on the inferior cava, cerebral veins, pulmonary artery, aorta, and other vessels.

§ 116. Circulation in the Spider.

In the spider a large dorsal vessel makes its appearance, this being dilated posteriorly so as to resemble a heart. The great propelling organ in the circulation in animals is now beginning to assume form. The dorsal vessel gives off lateral branches which ramify through the body; the venous blood being collected in open spaces or sinuses on the abdominal surface. There is as yet only an arterial system of vessels, the venous one being deficient. The blood is aërated by tracheæ or pulmonary cavities.

§ 117. Circulation in the Insect.

A similar account may be given of the circulation in the insect. Here the dorsal vessel is divided into a series of swellings, each of which is furnished with valves, and endowed with a pulsatile power, as shown at h of Fig. 127, p. 470. The dorsal artery receives lateral currents from various parts of the body, and is widened out posteriorly. The dorsal vessel opens and closes in parts (one part always opening when the other closes) with a vermicular or wave-like motion—this, in conjunction with the valves (x, r), determining the course pursued by the blood. The blood is returned by two vessels situated on the ventral aspect of the insect (v); these, according to Carus and Wagner, being in many cases absent, and their places supplied by open sinuses, as in the spider. The dorsal and ventral vessels are united anteriorly and posteriorly by loops which, in the immature or larval individual, extend into the antennæ, fin-shaped caudal processes, the first joint of each leg, and the immature wing. Under these circumstances the wings, antennæ, and caudal appendages act as respiratory organs.

In the insect the organs of respiration are also the organs of locomotion. The circulation is most complete, as a rule, in the immature insect. It is, however, quite perfect in not a few adult insects. Carus found it so in the wings of *Semblis*, developed for flight. In the fully matured insect the circulation in many cases becomes circumscribed, the blood being cut off from the several appendages and confined to the body. When the several parts are formed the vessels are either wholly or partly obliterated, as happens in the old vascular bundles of woody tissue in the more central parts of the tree. The insect is by this means rendered stronger and lighter for the purposes of flight. It is by the shrivelling, filling up, and obliterating of blood-vessels that organs, such as the branchiæ of the frog, and other fœtal structures which serve a temporary purpose, are lopped off. As the presence of blood is necessary to the existence of such structures, so its absence results in their destruction. The insect possesses a circulatory apparatus, which compels the blood to flow in given directions. The dorsal vessel of the insect consists virtually of a chain of hearts, which act in unison and in a certain rhythmic order, although they are more or less distinctly cut off from each other by the presence of valves. The caudal heart closes first (that immediately in front of it opening), and so on in regular order, that next the head closing last. The blood is driven forward by

[1] "Anatomy, Descriptive and Surgical," by Henry Gray, Esq., F.R.S., p. 401.

a rhythmic wave, or swallowing movement, and the valves are so placed that it must of necessity move in a circle. The peculiarity of the movement consists in the fact, that while one pulsatile cavity closes, another opens; each cavity opening and closing alternately, and every two cavities reciprocating and co-ordinating to produce a common result. In this way the blood, when expelled by the closing of one chamber, is received by another, which opens for the purpose. The dorsal vessel of the insect thus exerts a pushing and a pulling power, similar to that exerted by the œsophagus in swallowing.

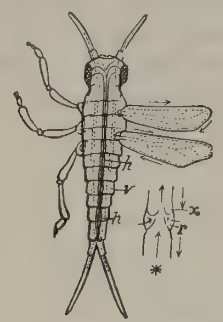


FIG. 127.—Shows the position of the vessels in the insect. *h*, Great dorsal vessel, consisting of pulsatile swellings which force the blood towards the head; *v*, vessels situated on the ventral aspect, which collect and transmit the blood in a direction from before backwards. The arrows indicate the direction of the currents in the wings. *, *x*, *r*, valves situated in dorsal vessel. Between these the lateral currents enter (*vide* small curved arrows). The valves are pushed aside and opened by the blood as it travels in the direction of the head (*see* arrows directed upwards), and forced towards the axis of the vessel, and closed by the blood when it attempts to travel away from the head (*see* arrows directed downwards) (after Thomson).

If any one of the pulsating cavities had, when it closed, forcibly to dilate that anterior to it, much power would be lost. The object to be attained by the closing of any one of the cavities is not to dilate that beyond it, but to force on the blood; and this object is best secured by any two cavities working in unison, the anterior one always opening when that behind it closes. In this way a *vis a fronte* and a *vis a tergo* are supplied. Each pulsating cavity, when it closes, exerts a pushing power, and, when it opens, a pulling power, so that each bead-like swelling of the dorsal vessel of the insect possesses all the attributes of the most highly differentiated hearts; in other words, it reverses its movements, so as to work in both directions, at one time acting as a *vis a tergo*, at another as a *vis a fronte*. This is a point of very considerable importance, as it invests pulsating sacs with a double function, literally no power being wasted. In the lobster, where there is only one pulsating sac, the double function is necessary. The arrangement affords a very good example of the "conservation of energy" in living tissues.

The heart of the chick greatly resembles a segment of the dorsal vessel of the insect. Thus it consists of a tube constricted at three points; the one part corresponding to the auricle, a second to the ventricle, and a third to the aortic bulb. These have the power of opening and closing rhythmically. The heart of the chick pulsates at a very early period, while it is yet a mass of nucleated cells, and before muscular fibres are developed in it (Fig. 128).

§ 118. Function performed by the Valves.

The valves situated between the pulsatile sacs of the dorsal vessel of the insect facilitate, as stated, the forward movement, but effectually prevent a retrograde or backward movement. As I shall frequently have occasion to allude to the valves as I proceed with the circulation, it may be as well briefly to refer to them on their first appearance. They consist of crescentic reduplications of the lining membrane of the vessels, around the interior of which they are festooned like garlands (Fig. 127, *, *x*, *r*). They diverge from the interior of the vessel in the direction of its axis, and as they are directed obliquely upwards and inwards with reference to the axis, they readily admit of the blood passing through them in the one direction, but effectually prevent its return. They may be compared to the folding-doors placed on the floor of a granary, which are opened by each bag of grain as it is made to pass from a lower to a higher level, but which flap together the instant the grain is elevated, to prevent its passing again in a downward direction. They, in fact, permit motion in only one direction. The valves are flexible elastic sluices, which are for the most part opened and closed mechanically by the blood—a few being closed partly by muscular movements. The free margins of the valves project into the interior of the vessels to such an extent that when the column of blood is at rest, they are more or less in apposition. The slightest reflux therefore instantly and effectually closes them. This action is the more instantaneous from the fact that behind the valves the vessels are scooped out to form sinuses, which contain a large quantity of residual blood; this, by its mere weight, greatly facilitating the closure. These sinuses I find in both the arteries and veins. They are known in the aorta and pulmonary artery of the human heart as the sinuses of Valsalva (Fig. 130, p. 471). The valves are found in infinite variety, and vary as regards the size, shape, number, and structure of their segments in the several orders of animals. As, however, they all act upon the same principle, and I shall have occasion to describe them minutely hereafter, I shall merely state that, when valves are present, the mystery as to the direction of the

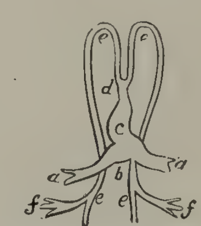


FIG. 128.—Heart of chick at thirty-seventh hour of incubation, seen from ventral aspect. *a*, *a*, Primitive veins; *b*, auricular portion of the heart; *c*, ventricular portion of the heart; *d*, bulbus arteriosus; *e*, *e*, primitive aortic arches, which subsequently unite to form the descending aorta; *f*, *f*, omphalo-mesenteric arteries (after Quain).

current or currents at once disappears ; for it is evident that if a long vessel furnished with valves closes at any given point, the fluid contained in it must move in the direction in which the valves open (*vide* arrows directed upwards of Fig. 127, *, p. 470).

The circulation in the insect is remarkable when viewed in connection with the respiratory system. As already stated, the body, and indeed every part of the insect, is tunnelled out by an innumerable series of minute elastic tough tubes, the so-called tracheæ. By their aid the insect breathes at every pore, very much in the same way that the plant breathes by its vascular and inter-vascular spaces, when these contain air. This is an interesting circumstance, as it shows the vast importance of constant relays of fresh air for the purposes of the circulation. The presence of air is a *sine quâ non ;* the fish has its gills, the reptiles their branchiæ or lungs, and so of the birds and mammals. The respiratory and circulatory systems more immediately connect the living organism with the outer world. In the stems of plants there are large air cavities, and not unfrequently the air and nutritive juices circulate together in the vascular bundles. In the lower animals, where the fluids transude, the air enters into combination with them ; and in the higher animals the blood in the lungs and other parts is barely separated from the air by a membranous film exceedingly thin and delicate in texture. In none of the animals which have hitherto been examined have we met with any one structure which could with propriety be designated a heart. This, in its simplest form, is to be found in the ascidia, which are provided with a pulsatile sac, consisting of thin membranous walls, apparently devoid of valves.

§ 119. Circulation in the Lobster—Position of the Respiratory Apparatus in the Lobster, Fish, &c.

In the lobster a structure is found which may be regarded as a true heart, alike on account of its position and shape, and because of the vessels which proceed from and return to it. The structure in question is situated below the posterior margin of the thoracic shield, and consists of an oval-shaped cavity or ventricle with muscular walls, as represented at *h* of Fig. 129.

The heart of the lobster has the power of opening and sucking or drawing the blood into it, and of closing and ejecting or pushing the blood out of it. These acts are equally vital in their nature, and it has occurred to me, from a careful study of the living organ, that the opening movement is the more vigorous of the two. The blood-vessels and heart act alternately and rhythmically. The heart gives off six systemic arteries, these conveying the blood to the system generally, and to the liver (*l*). The arterial blood is collected by veins which open into sinuses situated in the lower or ventral surface of the body. From these the branchial veins, which return the blood which has passed through the gills to the heart, arise. The heart, it will be observed, is a systemic heart, that is, a heart which forces the blood directly through the arteries, and only indirectly through the veins. It resembles, in some respects, the lymphatic hearts of reptiles and birds. When it closes, the blood is forced from the dorsal to the ventral surface of the animal, the fluid proceeding simultaneously in the direction of the head and tail. It then flows into sinuses or pouches, from which it passes through the gills on its way back to the heart. There is as yet no pulmonic heart present, and by this I mean a heart designed to force the blood directly into the aërating apparatus, whether this takes the form of gills or lungs. The circulation in the lobster, notwithstanding, naturally resolves itself into two parts, the presence of gills or aërating structures necessitating this degree of differentiation. The gills or aërating apparatus of the lobster are situated on its ventral surface, and in the track of the venous system, towards its termination ; that is, they are interposed between the terminal part of the venous system and the heart—the blood flowing from the heart towards the system, and from the system towards the gills. The same arrangement obtains in the cephalopoda. In the fish, as I shall show presently, an opposite arrangement prevails, the gills being situated at the beginning of the arterial system ; the blood flowing from the heart (ventricle) towards the gills, and from the gills towards the system. It is therefore a matter of little or no importance on what part of

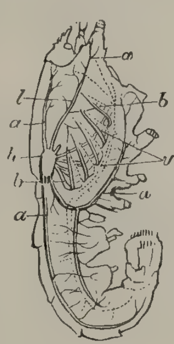


Fig. 129.

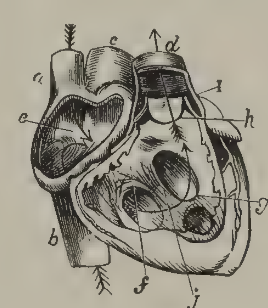


Fig. 130.

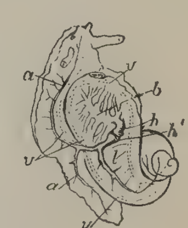


Fig. 131.

Fig. 129.—Shows the distribution of the blood-vessels in the lobster. *a*, *a*, *a*, *a*, Systemic arteries; *b*, *b*, branchial veins ; *v*, systemic veins and sinuses, from which the branchial veins arise ; *l*, artery conveying blood to liver and to branchiæ (the Author).

Fig. 130.—Pulmonic or right side of human heart. *e*, Right auricle ; *g*, right ventricle ; *a*, superior cava ; *b*, inferior cava ; *c*, aorta ; *d*, pulmonic artery ; *h*, segment of semilunar valve ; *i*, sinus of Valsalva ; *f*, segment of tricuspid valve ; *j*, musculus papillaris. The arrows indicate the direction in which the blood enters and leaves the right or pulmonic heart (after Gray).

Fig. 131.—Heart and vessels of garden-snail. *h*, Auricle ; *h′*, ventricle. *a*, *a*, arteries ; *v*, *v*, *v*, veins ; *b*, pulmonary sacs which receive the blood from the veins (after Thomson).

the circle representing the circulation the aërating apparatus is situated, so long as it occupies a position favourable to the exposure of the blood to the air. The blood flows in a continuous round, and it suffices if it be aërated at one part of its course, either by the aid of pulmonic sacs, gills, or lungs. As the respiratory system becomes more differentiated, its connection with pulsating cavities becomes more intimate. Thus in the bird and mammal the lungs are provided with a heart for themselves—the so-called pulmonic or right heart, which consists of two cavities : an auricle which receives the venous impure blood from the system, and a ventricle which forces the blood directly through the lungs where it is aërated (Fig. 130, p. 471). The left or systemic heart of the bird and mammal likewise consists of two cavities : an auricle which receives the aërated purified blood from the lungs, and a ventricle which distributes the aërated purified blood to the system. The heart of the bird and mammal consequently consists of four compartments. Between the most highly differentiated heart, as found in the bird and mammal, and that of the lobster, there is an infinite number of modifications, these mainly depending on the nature of the respiration. Thus in the fish the heart, as already stated, consists of two cavities—an auricle and a ventricle ; in the serpent of three—two auricles and one ventricle ; in the alligator the cavities virtually amount to four—the single ventricle being divided into two by an imperfect septum. It is therefore necessary to bear in mind, when speaking of the heart of animals, that it may consist of one, two, three, or four cavities.

§ 120. Circulation in the Brachiopoda and Gastropoda.

The brachiopoda have two aortic hearts, that is, two pulsating cavities situated on the principal artery of the body. The auricle and ventricle of a single complete heart are thus distinctly foreshadowed. Valves are also present. In the gastropoda and pteropoda, of the former of which the garden-snail may be taken as an example, there is a well-marked auricle and ventricle : the auricle receiving the blood from the pulmonary sacs, which obtain it from the veins ; the ventricle forcing it through the arteries (Fig. 131, page 471).

In the heart of the garden-snail the movements take place in the same order as in hearts of a higher type. Thus the auricle and ventricle pulsate alternately—the auricle closing when the ventricle is opening, and *vice versâ*. The rhythmic peristaltic movement which we beheld in the dorsal vessel of the insect reappears in a slightly modified form, the vermicular waves of motion being more isolated, and consequently more distinct. When a wave movement travels rapidly forward in a long vessel, it is difficult to say where it begins and where it terminates. This difficulty is in a great measure removed when, as in the present instance, the one cavity is observed to close, and then the other.

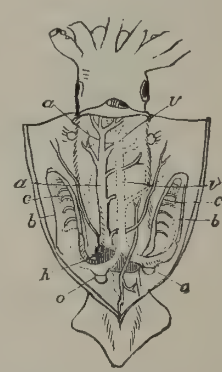


Fig. 132.—Heart and vessels of cuttle-fish. *h*, Heart ; *o*, *o*, dilated portions of vessels which lead to branchiæ, *b*, *b* ; *c*, *c*, branchial vessels ; *a*, *a*, arteries ; *v*, *v*, veins (after Thomson).

§ 121. Circulation in the Cuttle-fish.

In the cephalopoda, of which the cuttle-fish may be taken as the representative, we find a muscular systemic heart consisting of one cavity. To this may be added two dilated portions in the two vessels which lead to the branchiæ. These close and open like the heart itself, so that there are virtually two branchial cavities and one systemic one—three pulsating cavities in all. The connection between the circulation and the respiration is now becoming very obvious, and the pulsatile sinuses, situated near the root of the gills, may be regarded as harbingers of the pulmonic or right heart, as it exists in the bird and mammal (Fig. 132).

THE CIRCULATION IN ANIMALS (*Vertebrata*)

Hitherto we have been dealing with the invertebrata. In my remarks on the circulation of those most interesting and variously-constituted creatures, I have confined myself to no zoological classification, but have picked up a link of the chain wherever I found a suitable one. I have been able to show a gradual development of, and differentiation in, the channels and forces of the circulatory apparatus.

In the circulation in the vertebrata, to an examination of which I now direct attention, I shall be able to show a still higher degree of differentiation—not so much of the forces themselves, as of the organs or instruments by which the forces make themselves manifest.

§ 122. **Circulation in the Fish.**

In the fish we find a muscular heart consisting of two cavities, an auricle and a ventricle. The auricle receives the venous impure blood from the liver and the system generally, the ventricle forcing the blood through the capillaries of the gills (where it is aërated) into a large artery, which may be regarded as the homologue of the descending aorta in mammals. The blood contained in the great dorsal artery of the fish is arterial, that in the veins and heart venous (Fig. 133, p. 474). In addition to its general or principal circulation, the fish has two lesser or subsidiary circulations; namely, a circulation through the kidneys, and another through the liver. These lesser circulations reappear in the reptiles, and are interesting, the more especially as the portal circulation is also to be found in the mammal. When the principal circulation is once determined, any number of lesser circulations may be added without greatly increasing the complexity. The principal circulation, as has been explained, may be represented by a circle—the lesser circulation, by one or more loops grafted on the original circle. These loops may be added at any part, and may be increased indefinitely. Thus there may be a capillary, a renal, a portal, a pulmonic, and a cephalic circulation, &c.

The respiratory apparatus of the fish is placed on the arterial system. In the lobster and cuttle-fish, as has been shown, it is placed on the venous. This, however, occasions no difficulty. The heart of the fish, while consisting of only two cavities, has accessory structures of considerable importance attached to it. Thus the auricle is provided with a great venous sinus, which collects the blood destined to fill the auricle; while the ventricle is furnished with a muscular pulsatile organ, the so-called bulbus arteriosus, which assists the ventricle in forcing the blood through the gills. These several structures are deserving of separate description. The venous sinus, like its congeners, is a mere irregular dilatation or swelling, occasioned for the most part by the converging and flowing together of the principal venous trunks of the venous system. It may be compared to the vena cava of the mammal. The auricle is a somewhat irregularly shaped oval or angular chamber, having exceedingly thin muscular walls. The muscular fibres entering into its formation pursue no definite direction, but are grouped in such a manner as to secure great strength, and a large degree of pulsatile power. The shape of the ventricle in the most muscular fishes is that of an inverted three-sided pyramid.

In the heart of the salmon, which I have had frequent opportunities of dissecting, the ventricular walls are composed of muscular fibres which run in three well-marked directions, namely, vertically, transversely, and from without inwards. The vertical fibres are found on the outside and inside of the ventricle. In addition to being vertical they are also slightly plicated, a certain number of them passing through the wall of the ventricle, in a direction from without inwards or the converse. The vertical fibres, which may be regarded as forming an external and internal layer, are in many cases continuous at the base and apex of the ventricle. The transverse fibres occupy a central position in the ventricular wall, and pursue a more or less circular direction. The fish is thus supplied with an organ of great power, capable of opening and closing with a steady rhythmic movement. The bulbus arteriosus resembles, in its general appearance, the bulb of a hyacinth. It is muscular, and has a structure in many cases analogous to the ventricle itself. It receives the blood from the heart, and assists in forcing it through the capillaries of the gills, and thence through the system. A careful examination of the movements of the heart and bulbus arteriosus in the living pike, eel, trout, flounder, cod, shark, &c., has convinced me that the ventricle and venous sinus close when the auricle and bulbus arteriosus open, and *vice versâ*. The auricle supplements, as it were, the movements begun by the veins and venous sinus; the ventricle, those commenced by the auricle; and the bulbus arteriosus, those commenced by the ventricle. The relation of the auricle, ventricle, and aortic bulb to each other is to be inferred from the presence of valves between these structures, an arrangement which provides for combined and independent movements. Nor is this arrangement uncalled for. The close proximity of the gills to the heart would expose the capillaries of the gills to rupture if the ventricle closed with the violence necessary to force the blood through the entire system. This danger is averted by employing a second pulsatile cavity (the bulbus arteriosus), which, closing as it does with less vigour than the ventricle, keeps up but modifies the pressure within the required limits. We have an example of what mischief may be done by a too sudden and too violent closure of a pulsating cavity in the vicinity of capillaries, in cases of hypertrophy of the right ventricle of the human heart, where the pressure exerted not unfrequently produces rupture of the capillaries of the lungs—the pulmonary apoplexy of pathologists. The branches of the bulbus arteriosus correspond for the most part to the number of gill-plates; these in the cod-fish amounting to four on either side. The number of the branches varies: thus in the *Lophius piscatorius* there are only three, in most osseous fishes four, in the skates and sharks five, and in the lampreys six and seven. It is most interesting to observe that the arrangement of the vessels at the arterial bulb, and the beginning of the descending aorta, if we may so call it, is the same; the gills or respiratory system being introduced into the circulatory system as it were accidentally, or by the way. Thus, in the cod-fish, there are four main vessels given off

from the top of the bulb on either side of the gills, a corresponding number being given off from the gills to constitute the first part of what may be regarded as the descending aorta. (*Cp.* parts marked *a*, *a*, *b*, *b* of branchial plate, Fig. 133).

The arterial bulb of the fish is, in some respects, a remarkable structure. It is especially so as regards the number and nature of the valves contained in its interior. These vary in number, size, and shape, their segments ranging from two to thirty-two. In fact, in this single structure, every valve in the animal series is either indicated or actually represented. I defer a consideration of them till I come to speak of the valves as a whole. The number of the valves is in some measure necessitated by the pulsating properties of the bulb and the peculiar form of the respiration in fishes. The closing of the bulb is apt to interfere with the perfect action of the valves, and the proximity to the heart of the capillary vessels of the gills predisposes to regurgitation. In either case an increase in the number of valves is demanded.

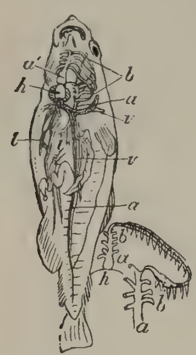


FIG. 133.—Heart and vessels of the fish (cod). *h*, Ventricle with auricle behind; *a'*, bulbus arteriosus, giving off four branchial vessels (*b*). These converge to form the first part of the descending aorta (*a*, *a*). *v*, *v*, Systemic veins receiving blood from liver (*l*), kidneys, &c.

The subjoined account of the movements of the heart of the fish, taken by myself from life, may prove interesting. The movements are rhythmical in character, and occur as follows :—

The large veins at the base of the heart close slowly and become paler in colour ; the auricle opening and becoming darker in colour. The auricle then closes energetically and suddenly, and changes from a dark purple colour to a reddish hue, the ventricle opening and assuming a dark purple colour. The ventricle now closes suddenly with a vermicular or wave-like motion, and assumes a reddish tinge, the arterial bulb opening and becoming of a purple colour. The bulb when it closes changes from a purple to a bluish or pearly white colour. The change of colour in the parts referred to is due to the presence or absence of blood in their interior. The veins and ventricle close when the auricle and arterial bulb open, and the veins and ventricle open when the auricle and arterial bulb close. The movements of the veins and ventricle co-ordinate those of the auricle and arterial bulb. There are no dead points. Before the veins have ceased to close, the auricle begins to open ; before the auricle has ceased to close, the ventricle begins to open ; before the ventricle has ceased to close, the bulbus arteriosus begins to open ; and so on in regular and uninterrupted succession. It occasionally happens, when the heart is more or less deprived of blood and acting slowly, that the auricle opens before the veins close, the ventricle in like manner opening before the auricle closes ; a circumstance which, in my opinion, proves that the *opening* of the auricle and of the ventricle is a vital act, in the same sense that the *closing* of each is a vital act. In other words, the opening of the auricle is not due to the closing of the veins and blood pressure, neither is the opening of the ventricle due to the closing of the auricle and blood pressure. The one movement contributes to the other, but does not cause it.

The auricle and ventricle (particularly the latter) open with considerable energy, so much so that the expansile movement may be felt when the heart is grasped between the finger and thumb.

The veins and arterial bulb shorten when they open, and elongate when they close. The auricle and ventricle, on the other hand, elongate when they open and shorten when they close. This difference is due to an excess of circular fibres in the veins and bulb, as compared with the number of these fibres found in the auricle and ventricle. The veins, auricle, ventricle, and arterial bulb are highly expansile. They flatten slightly when they open, and become rounded when they close. They increase and decrease by about a third during these movements. The veins act with less energy than the bulb, the bulb than the auricle, and the auricle than the ventricle. The action of the bulb is slow and sustained rather than rapid and violent. The auricle, ventricle, and bulb completely empty themselves of blood when they close.

The ventricle when closing rotates and twists slightly in the direction of its length. It also becomes shorter and narrower.

The apex of the ventricle describes an ellipse when the ventricle is opening and closing.

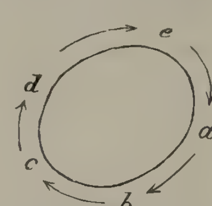


FIG. 134.—Track described by the apex of the heart of the fish. Enlarged (the Author, 1872).

I annex a diagram of the ellipse as bearing upon the much-disputed question of the impulse of the heart. The letter *e* (Fig. 134) represents the position assumed by the apex at the time the ventricle is closed and empty of blood. When the ventricle opens and receives the blood from the auricle, the apex travels in the direction *e*, *a*, and suddenly descends in a downward and outward direction, as shown at *a*, *b*. When the ventricle closes and ejects its blood, the apex describes the segment of the ellipse *b*, *c*, *d*, *e*, it being thus directed outwards, upwards, and inwards. The apex impinges against the thorax when it is describing the part of the ellipse *a*, *b*, *c*, *d*, and more particularly at *b*, *c*. There is no pause in the action of the ventricle from the time the apex leaves the point *e* until it returns to it. The ventricle expands between the points *e* and *b*. The ventricle as a whole flattens itself at this stage, and recedes from the anterior wall of the thorax, but its apex advances slightly towards it. The auricle closes when

the apex of the ventricle is travelling from *e* to *b*; and at this time the ventricle is most full of blood. The ventricle begins to close when the apex reaches *b*, the closing becoming more complete as the apex travels in the direction *b*, *c*, *d*, *e*. At *e* the closure is perfect and the ventricle empty of blood. From this it follows that the impulse of the heart of the fish corresponds neither to the diastole nor the systole of the ventricle, but to the termination of the diastole and the beginning of the systole. Of this I have fully satisfied myself.

§ 123. Circulation in the Batrachia.

The circulation in the aquatic reptiles, as it is found in the axolotl, proteus, menobranchus, siren, the larva of the frog, salamander, &c., falls now to be considered. The gills (branchiæ) in the axolotl and allied forms are situated outside the body, and are persistent. The gills of the larva of the frog, on the contrary, become covered as the animal develops, so that they assume the position and function of the gills in the fish. The heart in the protean reptiles consists usually of three cavities, namely, two auricles and a ventricle. The great point of interest in these remarkable creatures is the position of the gills, and the mixing of the arterial and venous blood in the ventricle. This is effected in the following manner:—The bulbus arteriosus, which may be compared to the first part of the aorta in mammals, divides into two; each division giving off three or more branches on either side, which extend along the arches formed by the hyoid bones, and break up into innumerable loops, to form the external gills, two branches, when lungs are present, going to them. The lateral vessels pass through the gills in a direction from before backwards, and reunite to form the descending aorta, so that the gills or respiratory apparatus are situated on the arterial or systemic system of vessels, as in the fish. When lungs are present they are furnished with pulmonary veins which proceed direct to the heart.

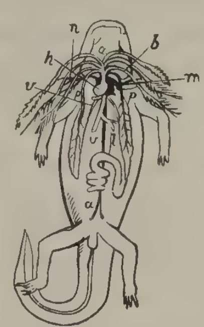


Fig. 135.

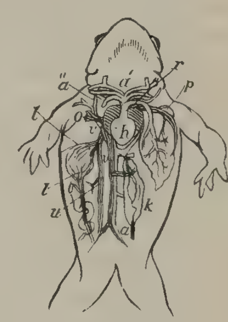


Fig. 136

Fig. 135.—Heart and vessels of axolotl. *h*, Ventricle; *m*, right auricle, receiving venous blood from the system generally (*v*, *v*); *n*, vessels from gills conveying arterial blood to the left auricle; *a* (superior), aortic bulb, dividing into eight branches, six of which go to the gills (*b*), and two to the lungs (*p*, *p*); *a* (inferior), descending aorta, formed by the reunion of the vessels which go to the gills; *l*, veins from liver (after Thomson).

Fig. 136.—Heart and vessels of frog. *h*, Ventricle with auricles above and behind; *a′*, aortic bulb splitting up into branches to supply the system and lungs. Of these some (*a″*) unite to form the descending aorta (*a*); others (those from the first part of the aortic bulb) going directly to the lungs; *v*, *v*, systemic veins; *l*, *u*, *k*, vessels going therefrom to the liver and kidneys (after Thomson).

The blood is projected from the ventricle into the capillaries of the gills and lungs. As the vessels from the gills reunite to form the descending aorta, the blood in the descending aorta is consequently red or arterialised blood. This pervades the entire body, and is returned to the right auricle by the systemic veins. The blood which circulated through the lungs is returned to the left auricle by the pulmonic veins. When the auricles close, the right one discharges venous blood into the ventricle, the left one arterial blood; the arterial and venous blood being mixed up in the ventricle accordingly. This result is facilitated by the fact that the interior of the ventricle presents a fretted, uneven, or broken surface, which is especially adapted for the triturating or mixing process. In some of the protean reptiles arterial twigs pass directly from the aortic bulb to the descending aorta. In such cases the blood is mixed in the descending aorta as well as in the heart; the blood which circulates through the body being partly arterial and partly venous (Fig. 135).

§ 124. Circulation in the Frog.

Having considered the circulation in the Batrachia, which respire principally by gills, I have still to describe the circulation in those which respire by means of lungs, such, for example, as the Chelonia, Ophidia, and Sauria. The adult frog naturally introduces us to this group. In the frog the circulation is very similar to that given above. Here the heart, as in the protean reptiles, consists of three cavities, two auricles and one ventricle. The lungs derive their vessels directly from the first part of the aorta, branches from the aortic arches uniting to form the descending aorta. The venous blood from the system returns to the right auricle, the arterial blood from the pulmonic veins returning to the left. When the auricles close, the blood is mixed in the ventricle as already explained. The venous blood, while making the circuit of the system, circulates by a special arrangement through the kidneys and the liver (Fig. 136).

The following description of the movements of the heart of the frog is taken from my notes made during the

life of the animal. The observations on which the description is based were made with extreme care on a large healthy frog immediately after capture, and before and after the pericardium was removed. The rhythm of the frog's heart essentially consists of four stages, traceable to the movements of the veins at the base of the heart, and to the movements of the auricles, ventricle, and bulbus arteriosus. The movements are essentially wave-like in character, the blood being forced through the structures referred to, by a kind of swallowing movement. The veins, auricles, ventricle, and arterial bulb act in pairs, as in the beaded dorsal vessel of the insect. Thus when the veins close, the auricles open; when the auricles close, the ventricle opens; when the ventricle closes, the aortic bulb opens; when the aortic bulb closes, the veins open; and so on in endless succession. These are vital movements, and go on when the heart is deprived of blood. From this it follows that the veins and ventricle open and close together; the auricles and bulbus arteriosus opening and closing together. As, however, the auricles open when the veins close, and the ventricle opens when the auricles close, while the arterial bulb opens when the ventricle closes, and the veins open when the aortic bulb closes, the sucking and propelling action of the various chambers through which the blood passes is brought fairly and fully into play. The blood is passed on by a series of definitely co-ordinated movements. When the heart is acting normally, one or other part of it is always moving. The instant the large veins begin to close, the auricles begin to open; and the moment the auricles begin to close, the ventricle begins to open. When the ventricle begins to close, the aortic bulb begins to open; and when the aortic bulb begins to close, the veins begin to open; and so on *ad infinitum*. It follows from this that the sounds of the heart, which are inaudible, are more or less continuous. The veins close slowly, the auricles somewhat suddenly; the ventricle less suddenly than the auricles, and the bulbus arteriosus less suddenly than the ventricle. The closure of the arterial bulb is a slow, sustained movement. The veins and auricles open slowly, the ventricle somewhat suddenly; the aortic bulb opens less suddenly than the ventricle, but more suddenly than the auricles.

When the veins close they present a light mauve colour, the auricles assuming a deep purple colour from the blood which they contain shining through their semi-transparent walls. When the auricles close a dark wave of blood is seen to enter the ventricle, the auricles becoming of a reddish, the ventricle of a purple, colour. When the ventricle closes it becomes pale red, the aortic bulb, when it opens, becoming a pale purple; when the aortic bulb closes it becomes of a bluish or pearly white colour, the veins at the base of the heart becoming a deep purple. The colour of the parts referred to depends upon the thickness of their walls and the quantity of blood which they contain at any given time. The veins, auricles, ventricle, and arterial bulb each reduce their dimensions by about a third when they close; they increase by a corresponding amount when they open. The different parts of the heart open and close by progressive wave-movements. The opening movement is centrifugal in character, the closing one centripetal. These are the only movements which can increase and diminish hollow chambers. Similar movements are observed in the opening and closing of the mushroom-shaped disc of the medusa, and the vacuoles or spaces of certain plants; those, for instance, of the *Volvox globator*, *Gonium pectorale*, and *Chlamydomonas*. The presence of muscular fibres is not necessary to such movements. The ventricle opens more suddenly than it closes; a remark which also holds true of the bulbus arteriosus. When the ventricle opens it flattens, its long diameter being increased; when it closes it becomes rounded, its long diameter being diminished. The apex and anterior wall of the ventricle strike the thoracic parietes towards the end of the diastole and the beginning of the systole, as in the fish. At this period the apex descends and advances towards the thorax. The apex during the diastole and systole describes an ellipse (Fig. 134, p. 474). The ventricle rotates slightly from right to left during the diastole, and from left to right during the systole.

The long diameters of the veins and auricles increase when those of the ventricle and bulbus arteriosus decrease, and the converse, the contents of the pericardium remaining nearly always the same.

The subjoined account of the movements of a snake's heart, written by me in 1865, is abstracted from my note-book:—When the heart is exposed, the auricles and ventricles are observed to open and close alternately. The movements in both cases are exceedingly slow, and apparently of about the same duration. The auricles and ventricle, particularly the latter, close in every direction—namely, from above downwards, from below upwards, and from without inwards. When the ventricle closes its anterior wall advances and strikes the internal surface of the thoracic parietes, the impulse being communicated during the ventricular systole.

The reptiles, which breathe chiefly by lungs, exhibit very considerable variation as to the structure of their hearts, the principal feature in which is the possession by many of a more or less complete septum ventriculorum. In certain of the reptiles the heart has virtually another cavity added to it; and it will be seen, that in proportion as the septum of the ventricle is rudimentary or complete, the circulation gradually advances from a single or mixed circulation to a double one; that is, a systemic and pulmonic.

§ 125. Circulation in *Lacerta ocellata.*

In the *Lacerta ocellata* a rudimentary septum ventriculorum makes its appearance.

It virtually divides the ventricle into two portions, these corresponding to the right and left ventricles of the bird and mammal. This necessitates a considerable modification in the arrangement of the great vessels at the base of the heart. In the fish, and protean reptiles, only one vessel proceeds from the ventricle, but in the present instance the anterior or right compartment of the ventricle gives off the pulmonic vessels, while the posterior or left compartment gives off the systemic. Provision is thus made to a large extent for a distinct pulmonic and systemic circulation, the right side of the ventricle forcing the blood through the lungs, the left side forcing it through the system generally. Before leaving the heart of the *Lacerta ocellata*, it is interesting to observe, that while the vessels emanating from the base of the ventricle are modified to suit the requirements of the almost double circulation, they nevertheless present in their groupings the general appearance presented by the branchial vessels of the fish where the circulation is single. We have here the remnants of an earlier form.

§ 126. Circulation in the Python, Crocodile, &c.—Presence of Septum Ventriculorum.

In the heart of the python the septum ventriculorum is nearly complete; in fact, the right and left ventricles would be quite distinct but for the existence of a small spiral slit in the septum posteriorly.

In the heart of the crocodile (*Crocodilus lucius*) the septum ventriculorum, as was pointed out by Hentz and Meckel, is fully developed, so that the ventricles of this animal are as perfect as those of either the bird or the mammal. The object to be gained by dividing the heart into four distinct compartments is obvious. By having two auricles and two ventricles, one auricle and one ventricle can be delegated to receiving the venous impure blood from the veins and forcing it through the lungs; the remaining auricle and ventricle receiving the arterial pure blood from the lungs, and forcing it through the system generally. The lungs on the one hand and the body on the other are each provided with a heart; hence the epithet double circulation, or, what is the same thing, pulmonic and systemic circulation. The peculiarity of the double circulation consists in the fact that the arterial and venous blood circulate separately as such, and are not mixed either in the heart or the vessels. This object, of course, can only be attained by increasing the chambers of the heart, and by keeping them separate from each other.

FŒTAL CIRCULATION

§ 127. Points of Analogy between the Circulation in Reptiles and that in the Human Fœtus.

It is not a little curious, that in the fœtal life of mammals many of the peculiarities of the reptilian circulation reappear. Thus in the fœtus the auricles communicate with each other by means of the foramen ovale, and the great vessels of the ventricles communicate by means of the ductus arteriosus.[1]

In the fœtus, therefore, the blood in the auricles and great vessels of the ventricles becomes more or less mixed up. As I pointed out on a former occasion, it is a matter of indifference where the respiratory apparatus is situated. It may occur in the venous system, as in the lobster and doris; or in the arterial system, as in the fish. The respiration of the mammalian fœtus affords a striking illustration of the accuracy of this observation. In the fœtus *in utero* the pulmonary organs perform no function whatever. They are ready for work, but, being in an unexpanded condition, are incapacitated. The arterialisation of the blood is therefore effected indirectly by the placenta, which is a temporary structure. To meet the requirements of such an arrangement the uterine vessels of the mother, and the vessels of the fœtus, are specially modified.

The fœtal circulation naturally resolves itself into two kinds, namely, the circulation within the body of the fœtus, carried on principally by the agency of the fœtal vessels and heart (these constituting the visible forces); and the circulation within the placenta and the tissues of the fœtus generally, carried on for the most part by absorption, evaporation, endosmose, exosmose, capillarity, chemical affinity, nutrition, &c. (these constituting the invisible forces). I shall first take up the visible circulation as it exists within the body of the fœtus, after which I shall proceed to examine the invisible circulation as it exists within the placenta.

§ 128. Circulation in the Body of the Fœtus.

The circulation within the body of the fœtus is a closed circulation; that is, its vessels and capillaries are continued upon themselves in such a manner as to form a series of circles of greater or less magnitude—the blood

[1] These openings occasionally remain pervious in the adult.

flowing within those circles in one continuous round. The blood is a mixed blood, being partly arterial and partly venous, the mixing taking place in the vessels and within the heart.

A mixed circulation amply meets the requirements of the fœtus, and is a positive advantage, as it places the fœtus in the condition of the reptilia, which are very tenacious of life, and endure much hardship without sustaining positive injury—qualities of the utmost importance to the fœtus *in utero*, the position of which is being constantly changed.

The fœtal circulation differs from the reptilian circulation, as to the temperature of the fluid circulated (the one being a cold, the other a warm blood); likewise as to the nature of the aërating apparatus, the blood of the fœtus not being aërated by branchiæ or lungs, but by the placenta, a temporary structure, improvised for the purpose. That the placenta performs the office of a lung to the fœtus is in great measure proved by the fact that if the umbilical cord be compressed before delivery the child makes vigorous efforts to respire by the mouth.[1] The placenta has for its object the close apposition of the capillary vessels of the mother and fœtus; this apposition enabling the fœtus to avail itself indirectly of the lungs of the mother. The fœtal circulation further differs from the reptilian in the important circumstance that the blood circulated is not produced and nourished by food taken into the alimentary canal, but by material absorbed from without; this material, in the later stages of pregnancy, being supplied by the blood in the uterine capillary vessels, and by the utricular glands of the mother, and applied indirectly by absorption, osmose, capillarity, chemical affinity, &c., to the capillary vessels or villous tufts of the fœtal portion of the placenta. The fœtus in this way indirectly avails itself of the stomach as well as of the lungs of the mother. The placenta consists of two elements, a maternal element and a fœtal element, and the function performed by it is essentially that of an alimentary canal and a lung. Professor Goodsir observes that "the external cells of the placental villi perform during intra-uterine existence a function for which is substituted, in extra-uterine life, the digestive action of the gastro-intestinal mucous membrane. The internal cells of the placental villi perform during intra-uterine existence a function for which is substituted, in extra-uterine life, the action of the absorbing chyle cells of the intestinal villi. The placenta therefore not only performs, as has been always admitted, the function of a lung, but also the function of an intestinal tube."[2] Between the maternal and fœtal portions of the placenta there is a line of demarcation, well marked in the earlier stages of pregnancy, but blurred and confused in the later stages; partly because of the very intimate and accurate apposition of the two parts of the placenta, which in not a few instances gives rise to abnormal adhesions; and partly because of the serrated nature of the opposing surfaces, and the presence of certain secretions. The line referred to forms at once the natural line of junction and separation between the mother and fœtus, and in a perfectly healthy parturition the fœtal portion of the placenta parts from the maternal portion in such a manner as not to rupture or destroy to any extent the mucous lining and capillary blood-vessels of the uterus of the mother. On the other hand, the mucous lining and villous tufts of the fœtal portion of the placenta likewise remain intact. This accounts for the fact that in the lower animals, and in a perfectly healthy human female, there is little if any hæmorrhage during parturition. The relation which the fœtus bears to the mother is that which the plant bears to the ground and the air; and that which the tissues of the adult animal bear to its alimentary canal and lungs, through which it obtains its nourishment and its breath. The capillary or villous tufts of the fœtal portion of the placenta represent the roots of the plant; the corresponding capillary tufts of the maternal portion of the placenta, the ground and atmosphere on which the plant subsists. The fœtus is in this sense to be regarded as a parasite, for it is a living thing living upon another living thing. This explains why a fœtus can take root and live upon other mucous surfaces than those supplied by the uterus, as, for example, those of the Fallopian tube; and I can quite understand that the fœtus would thrive on certain portions of the mucous lining of the alimentary canal, if we could only succeed in making a natural transference.

It is this intimate yet independent existence which enables us to consider the circulation in the fœtus as a thing *per se*. If we examine the fœtal portion of the placenta we find that the arteries and vein of the umbilical cord split up into innumerable capillary tufts, these minute vessels opening into and freely anastomosing with each other. While the capillary vessels of the fœtal portion of the placenta communicate with each other, they do not communicate with corresponding vessels in the maternal portion of the placenta; so that the fœtal blood, impelled by the fœtal heart and other forces, flows in a circle and gyrates in the body of the fœtus precisely as in the adult. The presence of the umbilical vessels and other fœtal structures, and the opening of the chambers of the fœtal heart directly and indirectly into each other, do not affect this gyration. We may begin at any part of the circle, but where we begin we must end, if we follow up the course of the blood. The umbilical vein, for example, extends between the placenta and the liver. It conveys arterial blood to the liver, and the ductus venosus (a fœtal structure),

[1] See a remarkable case related by Hecker, and the experiments of Schwartz, &c. *Vide* Casper's "Forensic Medicine" (*New Sydenham Society's Transactions*, vol. ii. p. 128, and vol. iii. p. 38).

[2] "Structure of the Human Placenta," by John Goodsir, Esq., F.R.S.L. and E., &c. ("Anatomical Memoirs," p. 460; 1845.)

which opens into the upper part of the vena cava inferior. In this latter situation the arterial blood originally supplied by the umbilical vein is mixed with the venous blood of the vena cava inferior. The vena cava inferior opens directly into the right auricle, and indirectly into the left auricle by the foramen ovale (a fœtal aperture). The Eustachian valve is, however, so placed that comparatively little of the blood (some say none) from the inferior cava finds its way into the right auricle, by much the greater portion passing through the foramen ovale into the left auricle. We have now got the mixed blood supplied by the upper portion of the inferior cava in the left auricle. This passes by the left auriculo-ventricular opening into the left ventricle. It proceeds thence into the arch of the

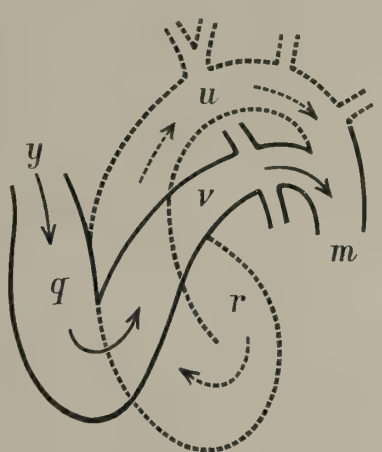
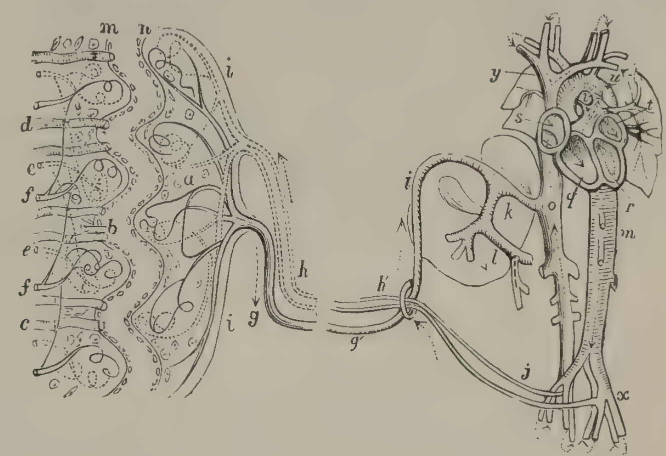


FIG. 137.



B FIG. 138. A

FIG. 137.—Diagram of the course pursued by the blood in the fœtal heart. *y*, Superior cava, the blood from which passes into the right auricle; thence into the right ventricle (*q*); thence into the pulmonary artery (*v*); and thence into the ascending (*u*) and descending aorta (*m*). *o*, Inferior cava, the blood from which passes behind the Eustachian valve (*s* of Fig. 138 A), through the foramen ovale, to the left auricle; thence to the left ventricle (*r*); and thence to the ascending (*u*) and descending (*m*) aorta. *u*, Arch of aorta and its branches (compare with similar letters of Fig. 138 A).

FIG. 138 A.—Diagram showing the course of the circulation in the human fœtus (*vide* arrows). *g′*, *i*, Umbilical vein, conveying arterial blood from the placenta; *h′*, umbilical arteries, conveying venous blood to the placenta; *k*, ductus venosus; *l*, vena portæ; *o*, vena cava inferior; *y*, vena cava superior; *s*, Eustachian valve and right auricle; *q*, right ventricle; *v*, ductus arteriosus, uniting aorta (*u*) and pulmonary artery; *t*, left auricle; *r*, left ventricle; *m*, descending aorta; *x*, common iliac artery, dividing into external and internal iliac arteries; *j*, hypogastric arteries, continuous with umbilical arteries (*h′*).

B.—Diagram illustrating the relation existing between the maternal (*m*) and fœtal (*n*) portions of the placenta (human). The maternal and fœtal surfaces are represented as separated from each other by a certain interval (*m*, *n*) to avoid confusion. They are slightly uneven from the projection into them of the maternal and fœtal capillary vessels. During pregnancy the two surfaces accommodate themselves so as to dovetail and fit accurately into each other. In the diagram the vessels represented by solid lines contain *arterial* blood; those represented by dotted lines *venous* blood. *m*, Mucous lining of uterus, with nucleated cells on its surface; *b*, sub-epithelial, spheroidal, and fusiform corpuscles, embedded in connective tissue; *c*, *d*, utricular glands lined with epithelium, and opening on mucous surface of uterus. They pour utricular secretion into utricular space (*m*, *n*). This space is mapped off, on the one hand, by the villi and coverings of the maternal portion of the placenta; and on the other, by the villi and coverings of the fœtal portion of the placenta. The utricular secretion is necessary to a free osmosis between the maternal and fœtal vessels (compare space *m*, *n*, with similar space at *f* of Fig. 141, p. 480; at *e* of Fig. 145, and at *i*, *f* of Fig. 146, p. 482). *n*, Limiting membrane of fœtal portion of placenta covered with nucleated cells; *a*, sub-epithelial, spheroidal, and fusiform corpuscles embedded in connective tissue; *i*, *i*, amnion; *g*, umbilical vein, conveying arterial blood to fœtus; *h*, umbilical arteries, conveying venous blood from fœtus. The umbilical arteries and vein break up to form the villi of the fœtal portion of the placenta; these being directed towards similar villi (*e*, *f*) constituting the maternal portion. The maternal and fœtal villi are separated from each other by the utricular space (*m*, *n*) containing utricular secretion; by two layers of cells, by two membranes, and by a certain proportion of connective tissue, spheroidal, fusiform, and other corpuscles (*a*, *b*).

aorta, and the right and left carotid and subclavian arteries; the head and superior extremities of the fœtus, which are comparatively very large and well nourished, being supplied by a purer blood than that furnished to the trunk and lower extremities. The blood returns by the jugular and subclavian veins, and vena cava superior, to the right auricle. It then passes through the right auriculo-ventricular opening into the right ventricle. It is impelled thence into the pulmonary artery; but as the lungs of the fœtus are in an unexpanded condition, and only receive so much blood as suffices for their nutrition,[1] the circulation would be stopped in this direction but for the existence of a temporary canal, the so-called ductus arteriosus, which unites the pulmonary artery and aorta at the aortic arch. Through this canal the more strictly venous blood from the head, superior extremities, and right side of the heart finds its way. The venous impure blood from the right side of the heart, and the nearly pure arterial blood from the left side, are thus a second time mixed. (The venous and arterial blood were first mixed in the

[1] In the fœtus *in utero*, the pulmonary organs take no part in the aëration of the blood. They are ready for work, but being unexpanded have no functional value. The probabilities are that the lungs, towards the full term, perform rudimentary rhythmic movements in anticipation of the function to be performed by them after birth, in the same way that the heart pulsates while yet a mass of cells, and before it contains blood.

upper part of the vena cava inferior.) The blood, twice mixed as it were, proceeds through the descending aorta and supplies the trunk, viscera, and lower extremities. The passage of the blood through the fœtal heart is indicated by the arrows in Fig. 137. It is not necessary to describe the circulation in the lower extremities at length. All that I wish to convey is, that the fœtal circulation is a complete or closed circulation. The aorta at its lower part divides into the common iliac arteries, which subdivide into the external, internal, and hypogastric arteries; the two former supplying the inferior extremities with blood. The venous blood is returned by the corresponding veins to the inferior cava, where it is joined by the arterial blood originally supplied by the umbilical vein. This completes one circuit of the circulation. The other circuit is formed by the hypogastric and umbilical arteries and vein, these constituting a very remarkable system of temporary canals; further proving, if more proof were required, that the chief function of the vessels is to convey the blood and nutritious juices through long distances. Vessels, as has been already shown, are not necessary to the circulation in the tissues. The chief point of interest in the fœtal circulation, as far as the heart is concerned, consists in the right and left auricles opening directly into each other by the foramen ovale; the right and left ventricles opening indirectly into each other by the ductus arteriosus, which unites their great vessels together.

The peculiarities of the circulation within the body of the fœtus are shown at Fig. 138 A, p. 479; those of the circulation within the placenta, at Fig. 138 B, p. 479 (*vide* arrows).

§ 129. Circulation in the Placenta.

The fœtal circulation thus far is not difficult to comprehend. The really difficult problem, and consequently the really interesting one, is the relation which the fœtal circulation bears to the maternal circulation. I have explained that the vessels of the mother and fœtus remain quite distinct in the placenta, and that in reality they are merely placed in intimate and accurate apposition. It is important to bear this fact constantly in mind. To understand this relation it will be necessary to recapitulate shortly, and to point out the relation which the external

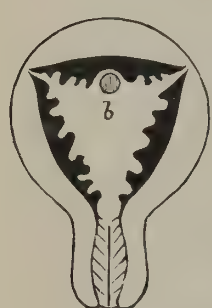


Fig. 139.

Fig. 140.

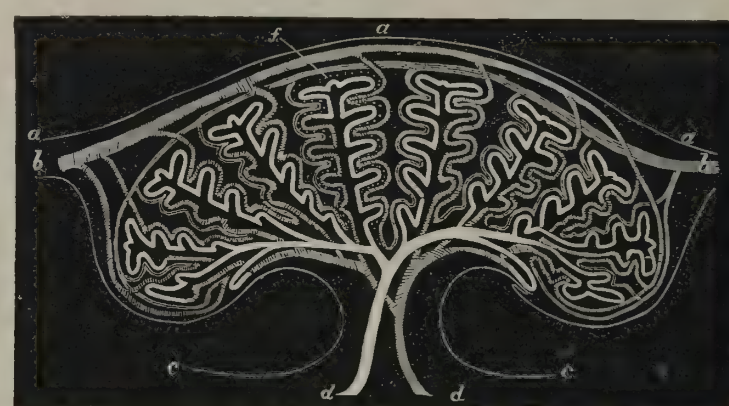


Fig. 141.

Fig. 139.—Impregnated human uterus, showing hypertrophy of the mucous lining or uterus (the decidua of authors). The mucous lining is represented in black, and the egg (*b*) is seen at the fundus of the uterus, engaged between two of its projecting convolutions (after Dalton).

Fig. 140.—Human ovum at end of third month, showing placental portion of the chorion fully formed. *h*, Chorion; *a*, villous tufts proceeding from chorion. These tufts at an early period completely invest the chorion, hence the epithet "shaggy chorion." When the chorion is shaggy the placenta is diffuse, as in the mare. *f*, Amnion; *x*, fœtus; *i*, umbilical vesicle (after Dalton).

Fig. 141.—Cotyledon of cow's uterus. *a, a*, Surface of fœtal chorion; *b, b*, blood-vessels of fœtal chorion; *c, c*, surface of uterine mucous membrane; *d, d*, blood-vessels of uterine mucous membrane (after Dalton). *f*, Secretion from utricular glands (cotyledonous milk) placed between maternal and fœtal vessels, and necessary to the mutual interchange of gases, nutrient, effete, and other matters, between parent and offspring (the Author, 1872).

and internal surfaces of animals—that is, skin and mucous membranes—bear to each other, and to corresponding parts of plants.

In an earlier part of the present work I directed attention to the analogy between the branches and leaves and the roots and spongioles of plants, and showed that these parts are essentially the same; roots in some cases giving off branches to produce leaves, and the stems of certain trees giving off branch-like processes which ultimately become roots. I explained that the surfaces exposed by the spongioles and roots, and the leaves and branches, are absorbing, secreting, and evaporating surfaces; the same surfaces at one time absorbing and secreting moisture, and at another excreting and evaporating it, according to the condition of the plant and the absence or presence of moisture,

heat, &c. This arrangement facilitates the circulation by favouring endosmose, exosmose, capillary attraction, and other physical forces, which, we know from experiment, perform an important part in the circulation in plants. The nutritious juices, I pointed out, are applied to the leaves and roots, and also, though to a less degree, to the stems of plants. I further explained that the animal has no roots to dig into the ground, or leaves to spread out in the sunshine, and that in this case the nutritious fluids and foods in the majority of instances are applied to an involuted portion of the animal's body, to wit, the mucous surface of its alimentary canal. But the mucous lining or internal skin of an animal is essentially the same as its external skin; the two bearing the same relation to each other which the roots and leaves of plants do; the mucous lining or internal skin of the animal corresponding to the roots of the plant, the external or true skin to the leaves of the plant. When therefore food in a more or less fluid condition is presented to the stomach and intestine, it is absorbed, and passes by osmose, capillary attraction, &c., through the animal in a direction from within outwards, first through the lacteals, and then through the vascular system and tissues of the body generally.[1] But fluids (in plants and animals) can be transmitted in an opposite direction, namely, from without inwards. This is shown in the case of shipwrecked mariners who immerse their bodies in the sea to slake their thirst, and in the inunction of the skin with oil and other nutritious fluids in cases of starvation from disease.

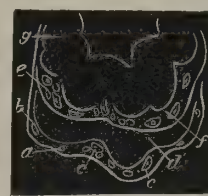


FIG. 142.

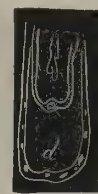


FIG. 143.

FIG. 144.

FIG. 142.—The extremity of a placental villus (human). *a*, The external membrane of the villus, the lining membrane of the vascular system of the mother; *b*, the external cells of the villus, cells of the central portion of the placental decidua; *c*, *c*, germinal centres of the external cells; *d*, the space between the maternal and fœtal portions of the villus; *e*, the internal membrane of the villus, the external membrane of the chorion; *f*, the internal cells of the chorion; *g*, the loop of umbilical vessels (after Goodsir, 1845).

FIG. 143.—This drawing illustrates the same structure as Fig. 142, and has been introduced to show the large space (*d*) which occasionally intervenes between the internal membrane and the external cells. It would appear that into this space the matter separated from the maternal blood by the external cells of the villus is cast, before being absorbed through the internal membrane by the internal cells. This space therefore is the cavity of a secreting follicle, the external cells being the secreting epithelia, and the maternal blood-vessel system the capillaries of supply. This maternal portion of the villus and its cavity corresponds to the glandular cotyledons of the ruminants, and the matter thrown into the cavity to the milky secretion of these organs (after Goodsir, 1845).

FIG. 144.—Diagram illustrating Dr. John Reid's views of the human placenta. *a*, Curling artery; *b*, uterine vein; *c*, uterine sinus formed by expansion of artery (*a*) and vein (*b*); *d*, fœtal tufts or villi, with inner coat (*e*) of vascular system (*a*, *b*) of mother enveloping them (after Dr. John Reid, 1841).

The transmission of fluids through the body, both from without and from within, is favoured by the respiration of the tissues, and the fact that evaporation goes on both in the mucous lining or internal skin, and in the external or true skin, these surfaces, as already stated, being essentially the same. The circulation within the tissues, as I have endeavoured to explain, is in a great measure independent of the heart, and due mainly to the operation of certain physical forces, namely, absorption, osmose, capillary attraction, chemical affinity, evaporation, &c. The heart and blood-vessels, when they exist, are employed for transmitting the nutritious fluids through long distances, in order to bring the blood and other juices face to face with the tissues, the constituent elements of which are so arranged that each takes—or one might almost say, has forced upon it, by the physical forces referred to—those particular ingredients which are best adapted for its development, maintenance, and reproduction. The object of these remarks is to show that the placental circulation of mammals is substantially the same as that of the tissues generally.

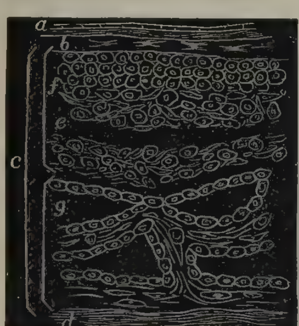


FIG. 145.—Diagrammatic section of human decidua at the termination of pregnancy. *a*, Amnion with epithelium; *b*, chorion; *c*, decidua; *d*, muscular coat; *e*, line of separation of the membranes of the ovum situated within the cell layer; *f*, cell layer of decidua; *g*, glandular layer of the same with epithelial cells (after Friedländer, 1870).

The ovum is extruded from what may be regarded as a mucous surface, namely, the interior of the ovary. It is grasped by the fimbriated extremity of the Fallopian tube, as by a hand extended to receive it, and conveyed to the interior of the uterus, in the mucous lining of which it is literally planted (Fig. 139, *b*).

The internal surface of the ovum (apparently its external one also) is applied to the internal or mucous surface of the uterus; but the internal surfaces of mother and fœtus are similarly constituted and perform analogous functions, the two coming together and blending as naturally as the fingers of the hands pass through and fit into each other. After a certain interval, processes equivalent to roots and "spongioles" are sent out from the internal surface of the fœtus (chorion) as seen at *a* of Fig. 140. Similar processes, which naturally exist in the uterine mucous membrane of the mother, become hypertrophied and exhibit a greatly increased activity. These processes of the mother and fœtus are at first distinct, a certain interval separating the two (Figs. 138, B, *m*, *n*, p. 479;

[1] The lymphatic vessels join the vascular ones—the chyle ultimately becoming blood.

139, *b;* and 157, *a*, *g*, p. 485). Gradually, however, they approach and interweave until they are accurately adapted to each other; the fœtus being as it were grafted on to the mother. Notwithstanding this very intimate relation, the fœtus and mother are essentially distinct. The fœtus is in some senses out of, or beyond, the mother, from the first. The arrangement is of a purely temporary character. The internal surface of the fœtus, or that part of it which constitutes the fœtal placental area, is quite distinct from the corresponding internal surface or mucous lining of the uterus which constitutes the maternal placental area. In the ruminants this relation is very well seen, the villous tufts which represent the fœtal portion of the cotyledon being torn out of corresponding tufts and depressions in the mucous lining, representing the maternal portion of the cotyledon, without rupturing the vessels, and in such a manner as to occasion no bleeding whatever. This arises from the fact that the capillary vessels of the fœtus and mother are simply laid against each other, that is, placed in juxtaposition; the two sets of vessels and the mucous linings investing them remaining essentially distinct. With a view to a natural and easy separation, the fœtal and maternal tufts in ruminants are arranged in wedge-shaped masses, the apices of the wedge-shaped capillary masses of the fœtus dovetailing into the capillary wedge-shaped masses of the mother, an arrangement which admits of very easy separation and extraction. The extraction is further facilitated by the presence of cotyledonous milk between the tufts (Fig. 141).

FIG. 146.—Diagram illustrating the placental arrangements in the whale (*Orca gladiator*). *c*, Utricular gland; *b*, funnel-shaped crypt into which utricular gland opens; *a*, cup-shaped crypt; *f*, *f*, epithelial layer lining crypts; *d*, fusiform corpuscles; *e*, *e*, spheroidal sub-epithelial corpuscles; *g*, *g*, close capillary plexus; *h*, *h*, fœtal villi projecting from chorion. These villi are invested by an epithelial layer (*i*, *i*). They consist of connective tissue which contains a layer of sub-epithelial corpuscles (*k*), of fusiform corpuscles (*l*), and a close capillary plexus (*m*, *m*), derived from the umbilical arteries, which plexus is continued into an extra-villous chorionic network (*n*, *n*) from which the umbilical vein arises. The fœtal and maternal vessels are not in contact, still less continuous with each other, but are separated by the layer of sub-epithelial corpuscles of the villus, the epithelial investment of the villus, the epithelial lining of the crypt, and the layer of sub-epithelial corpuscles of the crypt. The space between the two epithelial surfaces is intended to show the interval between the fœtal and maternal portions (of the placenta) into which the secretion of the uterine glands is poured (after Turner, 1871).

In the human female the relation between the fœtal villous tufts and those of the mother is more intimate than in any other animal, the tufts themselves being slightly club-shaped; but even here I am disposed to believe that the fœtal and maternal tufts are radically distinct, and that each is provided with its appropriate coverings; that, in fact, an open space exists between the two. This open space or neutral territory occurring between the maternal and fœtal placental tufts, I propose to designate the *utricular space*, from the fact that the utricular secretion or cotyledonous milk is poured into it. It corresponds, in my opinion, in the human subject, to the space marked *d* in Figs. 142 and 143, to *c* of Fig. 144, and to *e* of Fig. 145.

I have represented the utricular space at *m*, *n*, of Fig. 138, B (p. 479), and at *e*, *g*, of Fig. 157, p. 485). Professor (now Sir William) Turner has represented a similar space as occurring between the maternal and fœtal portions of the placenta of the whale (*Orca gladiator*), seen at *i*, *f*, of Fig. 146; a corresponding space found in the ox being shown at *f* of Fig. 141, p. 480).

FIG. 147.—Compound papillæ from palm of human hand (magnified). *a*, Base of papilla; *b*, *b*, *c*, branches of papillæ. Compare with Figs. 150 and 153 (after Kölliker).

FIG. 147.—Plan of a secreting membrane. *a*, Basement membrane; *b*, epithelium, composed of secreting nucleated cells; *c*, layer of capillary blood-vessels. Compare with *m*, *n* of Fig. 138, B, p. 479 (after Quain).

The utricular space is bounded by certain landmarks which it behoves us to study. They are essentially those of two mucous membranes or two portions of skin. The external and internal skin have many features in common, as I have already pointed out. The former consists of innumerable eminences or papillæ, the free surfaces of which display a mass of looped capillary vessels in all respects analogous to the placental villi or tufts. Between the papillæ an infinite number of tubes with blind convoluted extremities are found. These tubes open towards the free surface, and correspond to the sweat-glands. They secrete a peculiar fluid which is exhaled when we perspire.[1] Precisely similar remarks may be made of the internal skin or mucous lining of the alimentary canal.

[1] The number of sweat glands in the human body is incredibly great. Krause estimated that, on the skin of the cheeks, posterior portion of trunk, thigh and leg, they number 500 to the square inch; on the forehead, neck, forearm, back of hands and feet, and anterior part of trunk, 1000 to the square inch; and on the sole of the foot and palm of the hand, 2700 to the square inch. This observer estimated the number of sweat-glands in the body at 2,300,000; the length of glandular tubing amounting to 153,000 inches, or something like two and a half miles (Kölliker, "Handbuch der Gewebelehre"; Leipzig, 1852, p. 147). Lavoisier and Seguin estimate the quantity of fluid lost by cutaneous perspiration

Here we have a surface consisting of minute projections, filled with capillary loops, and studded with a vast array of tubular glands, similar, in many respects, to the sweat-glands and to the utricular glands or follicles of the uterus. The structures constituting the external and internal skin are shown in Figs. 147 to 154.

Here then, I submit, we have the elements out of which the placenta, when it exists, is formed, namely, two pieces of skin, or what is equivalent thereto, displaying innumerable eminences and depressions, an inconceivable number of capillary loops, and a vast array of utricular glands corresponding to sweat, gastric, intestinal, and other glands of that type (Fig. 138, B, p. 479). The mucous lining of the uterus displays a remarkably rich network of capillary vessels, looped and directed towards the peripheral surfaces and to all parts of the body. The capillaries are aggregated in parts like fairy rings in a field, and in the centre of the vascular rings the utricular glands or follicles open (Fig. 154). These glands secrete and exude an opalescent, slightly viscid fluid resembling milk, and which has from this circumstance been designated cotyledonous milk. The cotyledonous milk of the uterus supplies during gestation the nourishment afforded at a later period by the mammary glands. It also acts as an osmotic medium

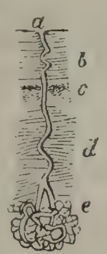


FIG. 148.

FIG. 149.

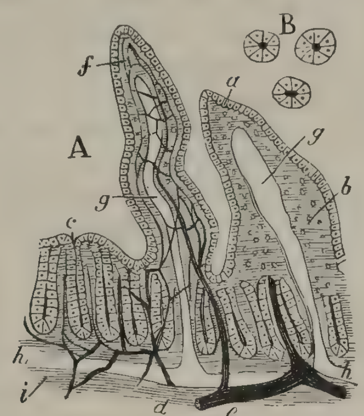


FIG. 150.

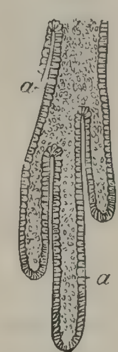


FIG. 151.

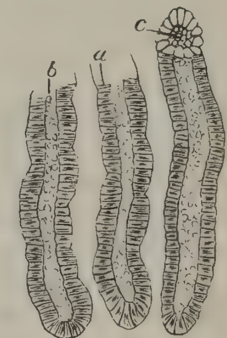


FIG. 152.

FIG. 148.—Sweat-gland and duct of human skin, opening upon surface at *a* (magnified). *e*, Gland surrounded by fat; *d*, duct of gland passing through corium, through lower (*c*) and upper part (*b*) of epidermis. Compare with Figs. 151 and 152, and with *c*, *d* of Fig. 138, B, p. 479 (after Wagner).

FIG. 149.—Ridges on epidermis of human skin, with orifices of sweat-glands (magnified). *a*, Ridge; *c*, furrow; *b*, orifice of sweat-gland. Compare with *a* of Figs. 154 and 155, p. 484 (after Quain).

FIG. 150, A.—Vertical section of two villi, from intestinal mucous membrane of rabbit $\frac{150}{1}$. *a*, Epithelium covering the villi (compare with *m*, *n* of Fig. 138, B, p. 479); *b*, substance of villi, with lymph-cells; *c*, tubular glands or crypts of Lieberkühn (compare with Fig. 152 and with *c*, *d* of Fig. 138, B); *d*, *e*, capillary artery and vein forming capillary plexus (*f*) in villus (compare with Fig. 153, p. 484); *g*, *g*, lacteal vessels of villi, joining horizontal lacteal (*h*, *h*); *i*, submucous layer.

B.—Cross section of three tubular glands more highly magnified (after Frey).

FIG. 151.—Deep portion of pyloric gastric gland, lined with cylindrical epithelium (*a*, *a*). From human stomach, magnified (after Kölliker).

FIG. 152.—Utricular glands from mucous membrane of unimpregnated human uterus (magnified). *a*, Lining of cylindrical epithelium; *b*, interior of utricular gland; *c*, orifice of utricular gland. Compare with Figs. 148 and 151 (after Dalton).

to the maternal and fœtal blood. The uterus and mammæ sympathise, and the lacteal fluids which they supply perform analogous functions.

Goodsir describes in the human subject two membranes and two sets of cells as interposed between the capillary loops of the mother and fœtus. These membranes and cells he separated from each other by a space, indicated at *d* of Figs. 142 and 143, p. 481. Sir William Turner has described a somewhat similar arrangement in the whale. He represents a fœto-maternal placental space, bounded on the one hand by the vessels and cell of the mother, and on the other by the vessels and cells of the fœtus. Thus, proceeding from the space in the direction of the uterus, there is, according to him, first, a layer of epithelium, and second, a layer of connective tissue, having embedded in it sub-epithelial, spheroidal, and fusiform corpuscles, and a close capillary plexus. Proceeding in the direction of the fœtus, a precisely similar arrangement obtains, there being, first, a layer of epithelium, an second, a layer of sub-epithelial, spheroidal, and fusiform corpuscles, in which a close capillary plexus is found (Fig. 146, p. 482).

Thus far the relation existing between the maternal and fœtal capillary vessels and their coverings is quite intelligible. The theories, however, advanced as to the transformations which the vessels and mucous membrane

in twenty-four hours at 13,770 grains, nearly two pounds avoirdupois (Robin and Verdeil, op. cit. vol. ii. p. 145). According to Dr. Southwood Smith, labourers engaged in gasworks sometimes lose by cutaneous and pulmonary exhalations as much as three and a half pounds in less than an hour ("Philosophy of Health," chap. xiii.; London, 1838). The effect produced on the circulation by the extraction of such large quantities of fluid from the system must in such cases be very great.

of the uterus undergo during the process of gestation have strangely, and, I feel assured, unnecessarily, complicated that relation.

First as to the mucous membrane of the uterus. There is nothing peculiar in this membrane, other than arises from an increased development of capillary vessels and contact with the villous tufts of the chorion; an ovum evolving as readily in the Fallopian tube as in the uterus. When impregnation takes place the uterine mucous membrane becomes greatly expanded, its component elements becoming excessively hypertrophied. It has, partly from this circumstance, but chiefly because it was erroneously supposed to be discharged at parturition, had its name changed from mucous membrane to decidua.[1] When the ovum enters the uterus, Sharpey and Coste believe that the uterine mucous membrane (the decidua of authors) rises up around it in the form of a wall, the free borders of the wall increasing until they unite and form a dome above it; the ovum becoming completely enveloped by the maternal lining or mucous membrane of the uterus.

FIG. 153.—Blood-vessels of intestinal villi, magnified (human). *a, a,* Arteries; *v, v,* veins. The artery and vein in each villus conducts to an intermediate capillary plexus or network. Compare with *e, f,* of Fig. 138, B; with *d, e, f,* of Fig. 150, A; and with Fig. 158, A, C, p. 486 (from Injection by Lieberkühn.)

Dr. Arthur Farre suggests another explanation. He supposes that the ovum, on entering the uterus, drops into one of the orifices leading to the utricular follicles, and, in growing there, draws around it the already formed, but soft and spongy, uterine mucous membrane constituting the walls of the cavity.[2] The ovum, according to these views, is buried at conception, and requires to be exhumed at parturition.

The mucous membrane of the pregnant uterus has for the foregoing reasons been artificially divided into three parts, known as the decidua vera, decidua reflexa, and decidua serotina. The decidua vera (also termed parietal) corresponds to that part of the mucous membrane which lines the uterus as a whole; the decidua reflexa to that part of it which is supposed to grow around and over the ovum; and the decidua serotina (supposed by some to be a new formation)[3] to that part of it which corresponds to the fœtal portion of the placenta, and with which it is directly or indirectly in contact[4] (Fig. 156, p. 485).

These views, I need scarcely add, are hypothetical, and the terms employed in explaining them arbitrary. As there are no sufficient anatomical proofs that the mucous membrane of the uterus during pregnancy deports itself as described, I propose abandoning the terms decidua vera, decidua reflexa, and decidua serotina. I will therefore, when describing the lining membrane of the uterus, refer to it simply as such, always specifying the portion meant.

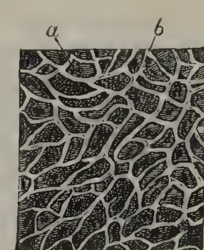


FIG. 154.

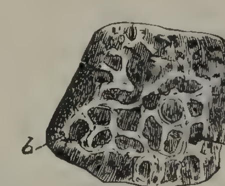


FIG. 155.

FIG. 154.—Network of capillary vessels (*b*), with orifices of utricular glands (*a*), as seen on surface of mucous membrane of human uterus (magnified). Compare with same letters in Fig. 155 (after Farre).

FIG. 155.—Network of capillary vessels (*b*), with orifices of gastric glands (*a*), as seen on surface of mucous membrane of human stomach, magnified (after Ecker).

That the uterine mucous membrane does not require to grow around and over the ovum during pregnancy is proved by this, that in extra-uterine fœtation the uterine mucous membrane is absent. Similar remarks apply to Fallopian-tube gestation, although here the conditions more closely resemble those found in the uterus.[5] In pregnancy, whether extra-uterine or intra-uterine, the mucous membrane, capillary vessels, utricular glands, and muscular fibres of the uterus, increase in size and activity. There are two admirable specimens of Fallopian-tube pregnancy in the Museum of the Royal College of Surgeons, Edinburgh, in which the uterine structures have

[1] In the posthumous work of Dr. William Hunter ("An Anatomical Description of the Human Gravid Uterus"), edited by Dr. M. Baillie in 1794, the decidua is described as under:—"This membrane is an efflorescence of the internal coat of the uterus itself. . . . It may be said to be the internal membrane of the uterus. . . . It is really the internal lamella of the uterus."

[2] This hypothesis is based upon what may turn out to be a purely accidental occurrence, namely, the discovery by Bischoff of the presence in the guinea-pig of an ovum in the bottom of a uterine follicle.

[3] "At the part where the uterine expansion of the decidua is interrupted by the reflexion inwards of the decidua reflexa, and where the ovum entered, the place of the decidua vera is supplied by *another layer similar to it,* and connected at its margins with it, the decidua serotina." ("Kirkes' Physiology," p. 661, 3rd edition, 1856.)

[4] Dr. Arthur Farre is of opinion that the decidua reflexa is in part formed out of the parietal decidua (decidua vera) from the number of orifices of utricular glands seen on its surface. He, however, admits that much is due to the further development of the elemental decidual tissues, this increase being principally due to the large supply of blood-vessels furnished to the decidua reflexa at an early period.

[5] As the Fallopian tube opens into the uterine cavity the two are anatomically continuous.

become hypertrophied by sympathy; the os uteri being curiously enough closed by a plug of mucus. Extra-uterine and Fallopian-tube pregnancies induce me to believe that the ovum brings with it or develops its own membranes;[1] the conditions necessary being heat, moisture, and a mucous surface, either within or without the uterus. The chick only derives heat from the body of the mother. When the ovum reaches the interior of the uterus, it applies its chorionic (which is in reality its mucous) surface to some portion of the mucous surface of the uterus. At first the two mucous surfaces are quite distinct, the relation being that rather of apposition than actual contact. As pregnancy advances the maternal and fœtal mucous membranes, and the vessels which underlie them, become developed (particularly in the region which corresponds to the placental area). The membranes and vessels become entangled, adhere, and interweave in a most remarkable manner (Fig. 138, B, p. 479, and Fig. 157).

FIG. 156.—*x*, Chamber occupied by ovum; *b*, *c*, decidua vera; *d*, decidua reflexa; *g*, decidua serotina. Compare with same letters in Fig. 157 (the Author, 1872).

The advantage of this arrangement consists in the fact that it secures to the mother and fœtus an independent and yet a common life, the fœtus being to the mother in the relation of a parasite. It further secures independence and community of structure.

Thus the fœtus has its mucous lining (*d*, *e* of Fig. 157), and the mother her mucous lining (*g*, *b*, *c* of Fig. 157); the fœtus has its capillary zone, consisting of villous tufts (*h*, *a* of Fig. 157), and the mother has a corresponding capillary zone, the capillaries found on the mucous lining of the uterus (*e*, *f* of Fig. 138, B); the mother has utricular glands (*c*, *d* of Fig. 138, B); the fœtus their homologues. The fœtus, as gestation proceeds, concentrates and augments its villous tufts and vascular supply (*a* of Fig. 157; *a* of Fig. 140, p. 480; *i*, *n* of Fig. 138, B); the maternal vessels, within the placental area, becoming correspondingly developed (*e*, *f* of Fig. 138, B), and the blood-supply correspondingly increased. This community of structure and of life secures the ovum and subsequent fœtus the fullest opportunities for nourishment and development. In normal pregnancy the ovum, from the time it enters the uterus, is in contact with the uterine mucous lining. It bring with it an independent life and independent structures, and it is the blending of that life and those structures in the placental area for a certain period with the life and structures of the parent, that constitutes the mystery of conception and gestation.

FIG. 157.—Plan of section of uterus with fully formed ovum (human). *g*, Mucous lining or membrane of uterus, opposite placenta (decidua serotina of authors); *b*, *c*, lining membrane on body of uterus (decidua vera of authors); *d*, lining membrane of fœtus (decidua reflexa of authors). This membrane (*e*) is found on the free surfaces of the chorionic villi (*a*), being in fact the mucous lining of the chorion. Such parts of it as are not engaged in covering the chorionic villi become thinned away and disappear towards the full term. It may, however, always be found on the free or uterine surface of a normal placenta. *a*, Chorionic villi constituting fœtal portion of placenta (the maternal portion is formed by capillary vessels found in mucous lining, *g*); *h*, chorion, from which the chorionic villi spring; *f*, amnion; *i*, umbilical vesicle; *j*, Fallopian tube.
Note.—As pregnancy advances the parts marked *e*, *a*, *g* approach each other, and become accurately apposed. The same holds true of the parts marked *b* and *d*. This apposition and blending of maternal and fœtal structures facilitates the exchange (chiefly by osmosis) of nutritive and effete materials between parent and offspring (the Author, 1872).

The mucous membrane of the chorion (the *decidua reflexa* or *decidua ovuli* of authors) increases in the same ratio as the ovum, which it incloses and protects. The receptacle containing the ovum is a small chamber placed within a larger one, namely, the uterine cavity. Those surfaces of the fœtal and maternal chambers which are directed towards each other are each provided with a mucous lining. The walls of the fœtal and maternal chambers are only in apposition at first; but as development proceeds the fœtal chamber becomes fixed to the maternal one, and protrudes from it like a spherical bud. The cavities of the chambers nevertheless remain quite distinct. On the mucous lining of both the fœtal and maternal chambers, orifices of utricular glands or their homologues can be made out—a circumstance of considerable importance, as showing that the fœtal portion of the placenta is supplied with utricular glands as well as the maternal portion. A large number of vessels, terminating in minute capillary plexuses, are found on the mucous surfaces of both the fœtal and maternal chambers. These interdigitate at an early period. The ovum at first lies loose in the fœtal chamber, but becomes fixed in it towards the end of the first month. The fixing is effected by

[1] "The ovum during its passage along the Fallopian tube acquires a layer of albumen, and this subsequently coalesces with the zona pellucida to form the chorion" ("Kirkes' Physiology," p. 676, 3rd edition, 1856). The villi of the chorion consist at first entirely of cells, bounded by an external layer of textureless membrane, which gives their form (Goodsir). If a normal placenta be examined after delivery, a distinct membrane can be traced on its uterine surface; that is, the surface corresponding to the uterine placental area. This membrane I am disposed to consider the mucous membrane or lining of the chorion.

the aid of villous processes which project from all parts of the chorion (hence the epithet shaggy chorion). They suspend and fix the ovum in the fœtal chamber as a spider is suspended and fixed by its web. The embryo, surrounded by its amnion, chorion, and mucous lining, in this manner becomes securely anchored in a haven of its own forming. Other changes succeed. As the ovum grows, the villi of that part of it which is in contact with the mucous lining of the uterus increase in size, and become more ramified. The villi of the maternal placental area become correspondingly developed. Dissepiments or partitions of mucous membrane also make their appearance, and divide the maternal and fœtal villi into groups, producing that lobed appearance so characteristic of the fully-formed placenta. The lobes of the human placenta are in reality the homologues of the cotyledons of the ox.

The ovum, as stated, brings a certain amount of nourishment with it; the rest it obtains by imbibition, due to contact with the mucous membrane of the uterus, and the utricular secretion which it there finds. Long before blood-vessels make their appearance in the embryo, a circulation of nutritious juices, similar to that found in plants and the lowest animal organisms, is established. This is effected by osmose, due to the presence of membranes and fluids of different density. The membranes are seen at Fig. 157, p. 485. They consist of the capillary blood-vessels of the interior of the uterus (*e*, *f* of Fig. 138, B, p. 479), the mucous membrane of the uterus (*g*, *b*, *c* of Fig. 157), the mucous membrane and capillary blood-vessels of the chorion (*e*, *a*, *h* of Fig. 157), and the amnion (*f* of Fig. 157). There is every reason to believe that the maternal and fœtal membranes when in contact, as in pregnancy, not only act as osmotic media, but also as secreting media. Goodsir, as has been pointed out, attributed a secreting power to the membranes and cells covering the extremities of the placental villi. These, according to him, consist of an external membrane and nucleated cells, and an internal membrane and nucleated cells. Between these a space occurs, which he regards as the cavity of a secreting follicle (Figs. 142 and 143, *d*, p. 481). The external membrane corresponds to the mucous lining of the uterus, which I believe it really is; the internal membrane to the outer surface of the chorion. This, as explained, I regard as the mucous lining of the chorion.

Fig. 158.—A, Extremity of fœtal tuft of human placenta. From an injected specimen, magnified forty diameters. Compare with vessels in Fig. 138, B, p. 479.
B. Compound villosity of human chorion, with ramified extremity. From a three months' fœtus, magnified thirty diameters.
C. Extremity of villosity of chorion more highly magnified, showing the arrangement of the blood-vessels in the interior (after Dalton).

The chorion and mucous surface of the uterus are, as a rule, highly vascular. I have succeeded in minutely injecting the arteries and veins of the chorion and amnion of the mare;[1] and injections of the membranes of the ox, sheep, and other domestic animals are to be found in nearly all our museums.[2] The mucous membranes of the uterus and chorion, with their cells and blood-vessels, may with great propriety be compared to secreting structures composed of a basement membrane, nucleated cells, and capillaries (Fig. 147, p. 482); and they apparently only require to be brought together to inclose a space to enable them to assume the secreting function.

The desired space is obtained immediately the ovum comes in contact with the mucous lining of the uterus. At first the uterine mucous membrane and utricular glands are more especially engaged in secreting; the product passing by endosmose and imbibition directly into the ovum; the ovum returning its peculiar fluids by exosmose. The transference of liquid materials is greatly facilitated by the formation, in the first month of pregnancy, of the shaggy chorion. This structure is composed of an immense number of villous tufts, consisting of a membrane of nucleated cells within which capillary blood-vessels are ultimately developed (Fig. 158, A, B, C).

The villous tufts are at first short, club-shaped processes of uniform size. They are not attached to the mucous lining of the uterus, so that the embryo floats freely and obtains its nourishment after the manner of water-plants, namely, by imbibition. The club-shaped villi, as Goodsir pointed out, elongate by additions to their extremities as in the roots of plants; cells passing off from the germinal spots situated on the ends of the villi. Goodsir demonstrated that blood-vessels appear in the chorion and chorionic villi when the allantois reaches and applies itself to a certain part of the internal surface of the chorion. At this stage of development the umbilical vessels communicate with vascular loops in the interior of the villi. The injections of Schroeder van der Kolk showed a profusion of capillary vessels in the chorionic villi as early as the third month; and at later periods of gestation up to the sixth month Dr. Arthur Farre succeeded in displaying without difficulty, by the aid of fine injections, a very abundant supply of these vessels. At a later period, a large proportion of the fine capillaries within the villi disappear, the long, tortuous, varicose loops described by Goodsir alone remaining. From this it follows that the blood-vessels engaged in nourishing the fœtus have a period of development, a period of increased activity, and a period of

[1] These and other preparations bearing upon the placenta are to be found in the Hunterian Museum of the Royal College of Surgeons of England, London.
[2] Particularly fine specimens of placentæ and membranes are to be seen in the Anatomical Museum of the University of Edinburgh, the majority of them injected by Goodsir.

decay; the period of decay heralding, if not actually producing, parturition. These changes are necessary to inaugurate the circulation in the fœtus, to unite the circulation in the fœtus with that in the mother, and to separate that connection at the period of parturition.

The fluids concerned in the nutrition and well-being of the fœtus are such as are supplied by the utricular glands and by the various secreting surfaces, maternal and fœtal. The utricular glands in the early months of pregnancy supply a milky fluid, nutritive in character, which, as has been explained, acts as an osmotic medium to the fluids contained without and within the fœtal chamber. Of the fluids contained within the fœtal chamber the substance of the embryo imbibes freely. In the later stages of pregnancy, when the placenta is fully formed, the utricular secretion produces an osmotic action between the blood contained in the placental villi of the fœtus and that contained in the capillaries of the placental area of the mother (*vide* Fig. 159).

There is reason to believe that, even in advanced pregnancy, the surface of the fœtus imbibes nutritive materials from the fluids in which it is suspended, and by which it is constantly bathed. This it can readily do, as the external skin of the fœtus is so delicate that it in some respects resembles the mucous membrane of the adult. The external skin of the fœtus in intra-uterine life in all probability absorbs, and exercises a secreting function; whereas in extra-uterine life it respires, and exercises an excreting function. As I showed in plants, certain surfaces may act either as absorbing or respiring surfaces, according as they are exposed to the influence of moisture or air (Figs. 111, 112, and 117).

I have stated that Goodsir divided the membranes and cells found by him on the extremities of the placental villi into an external and internal set; and that, in my opinion, the external membrane and cells constitute the mucous or lining membrane of the uterus.

Goodsir has, it appears to me, transferred the mucous lining of the uterus to the mucous lining of the chorion; a not unnatural transference, when it is remembered that, in not a few instances, particularly in highly civilised females, artificial adhesions are formed, and the fœtal half of the placenta drags with it at parturition a portion or all of the maternal half. To this circumstance, in all probability, is to be traced the difficulty experienced by anatomists in determining whether the uterus does or does not, shed its mucous membrane after each parturition.[1] This would explain why there should be a space between the external and internal membranes covering the extremities of the placental villi, as described by Goodsir; the space being the natural line of junction and separation between the maternal and fœtal portions of the placenta.[2] It would also account for the belief entertained by him, by Reid, Ecker, and others, that the maternal blood-vessels (arteries and veins) within the placental area become enormously expanded, and envelop by bladder-like dilatations the villi of the fœtal portion of the placenta

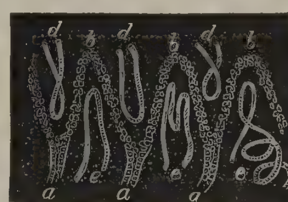


Fig. 159.

Fig. 160.

Fig. 159.—Diagram showing the placental relations of the maternal and fœtal capillaries, and the position occupied by the utricular secretion. *a, a, a,* Utricular glands, pouring out utricular secretion (*b, b, b*); *e, e, e,* maternal capillary plexuses (with artery and vein) as seen on interior of uterus; *d, d, d,* fœtal capillary plexuses with artery and vein as seen on surface of placenta, directed towards interior of uterus. The maternal and fœtal linings and epithelial corpuscles which separate the maternal and fœtal villi are not represented. The presence of the utricular secretion (*b, b, b*) between the maternal and fœtal vessels necessitates a free interchange of the ingredients peculiar to each. See also under *f* of Fig. 141, p. 480 (the Author, 1872).

Fig. 160.—Diagram illustrating the arrangement of the placental decidua (human). *a,* Parietal decidua; *b,* a venous sinus passing obliquely through it by a valvular opening; *c,* curling artery passing in the same direction; *d,* lining membrane of the maternal vascular system, passing in from the artery and vein, lining the bag of the placenta, and covering (*e, e*) the fœtal tufts, passing on to the latter by two routes, first by their stems from the fœtal side of the cavity; and, secondly, by the terminal decidual bars (*f, f*) from the uterine side, and from one tuft to the other by the lateral bar (*g*). This membrane is in contact with decidual cells, unless along the stems of the tufts and the fœtal side of the placenta. Compare with Fig. 143, p. 481 (after Goodsir, 1845).

[1] In man the tissues, as a rule, are more highly elaborated than in animals—a circumstance which renders their separation more difficult. Dr. Arthur Farre, in his work "On the Uterus and its Appendages," states that, "in the latter months of pregnancy, the parietal decidua (that is, the mucous lining of the uterus) becomes thinner, and loses much of its spongy character, except immediately around the placenta, where this is still most distinct. It ultimately becomes blended with the outer surface of the fœtal membranes, and is partly thrown off with them in the act of birth, while a part remains, forming a honeycomb layer attached to the uterine muscular coat." My interpretation of this is that the decidua of the placental area admits of division, one part being shed with the placenta at parturition, the other remaining on the interior of the uterus. In reality the placenta takes its own mucous lining with it, the uterus retaining the mucous lining which belonged to it before conception took place. If we examine a normal placenta when thrown off at full term, we find a membrane on its free or uterine surface; and if we examine the placental area of the uterus which corresponds thereto, we find a similar membrane. This is what we would *à priori* expect. Why should the placenta at parturition drag off any part of the decidua or mucous lining of the uterus? The maternal and fœtal structures are distinct from the first, and so remain. They separate as naturally and with as little inconvenience as they come together.

[2] From the foregoing it will be evident that I do not regard the placenta as structurally united to the uterus, but simply as in apposition and adhering, the union being of the most intimate description, from the fact that the maternal and fœtal villi pass through each other so thoroughly that they form with their contained blood a semi-fluid mass. The placenta is to the fœtus what the roots are to a parasitic plant (the mistletoe, for example). The fœtus, by its placenta, literally plants itself on the inner surface of the uterus, this supplying it with nutritious juices and with air.

(Fig. 144, p. 481, and Fig. 160, p. 487). If, as I presume, in the specimens examined by Goodsir, Reid, Ecker, and others, the villi of the fœtal portion of the placenta dragged with them at parturition the villi of the maternal portion, the result would be exactly that figured and described, namely, a large spongy mass, containing blood sinuses, with occasional villi proceeding from or dipping into them. During pregnancy the vessels of the uterus, particularly the veins, assume gigantic proportions, the blood contained within the organ causing it in some respects to resemble a lung; but the blood-vessels increase in a progressive ratio with the nerves, glands, muscular, mucous, and other tissues, and there are no sufficient grounds, anatomical or physiological, for supposing that during the hypertrophy which occurs during pregnancy, the maternal capillary vessels corresponding to the placental area cease to exist as such; in other words, become converted into the bladder-like expansions referred to. Such a metamorphosis would remove the human placenta out of the category of mammalian placentæ; a removal which neither its origin, progress, nor final dehiscence warrants.[1]

One naturally inquires, when contemplating the enormous maternal vascular expansions represented by Reid (Fig. 144), Goodsir (Fig. 160), and Ecker, where the material comes from which produces them? The additional material required on the part of the curling arteries and veins of the uterus to envelop every villous tuft contained in the fœtal portion of the placenta, is such as virtually to render the hypothesis untenable. So far as is known to me, there is no other example of a modification on a similarly gigantic scale in any natural structure. If the terminal portions of the curling arteries and veins of the uterus were expanded to the extent described, and if, moreover, they embraced and became locked within the villous tufts of the fœtal portion of the placenta, as figured, then of necessity the whole of that portion of the interior of the uterus corresponding to the placental area would be converted into an open wound when the placenta was removed; the wound exhibiting on its surface an incredible number of large bleeding vessels, which no degree of contraction on the part of the uterus could either modify or restrain. What however is the real state of things? During a healthy parturition scarcely any blood is lost, and on examining that portion of the interior of the uterus corresponding to the placental area, it is found covered with a mucous membrane somewhat resembling a honeycomb—an appearance caused by the apposition and interpenetration of the mucous membrane and villi of the fœtal portion of the placenta. On examining the free or uterine surface of the placenta, a similar membrane is discovered; the one, in fact, being the counterpart of the other.[2] If a normal full-term placenta is injected with size after its removal, there is little if any extravasation from its free or uterine surface; plainly showing that it is bounded by its own peculiar mucous membrane. All the difficulties and dangers referred to are avoided by regarding the fœtal and maternal portions of the placenta as essentially distinct, not only in the early but also in the later months of pregnancy. The structures in question are simply in temporary apposition (Fig. 138, B, p. 479). This view insures, as stated, an independence and community of structure. It assimilates the human with the placentæ of other mammals. It accounts for the fact that a fœtus may be developed in the Fallopian tube, or outside the uterus altogether. It in especial explains how the ovum can be applied to the incubating chamber of the mother, and how the fœtus may be separated from it, without causing either injury or inconvenience. Lastly, it shows that the maternal and fœtal developments which constitute a pregnancy are correlated, the one advancing *pari passu* with the other.

As a proof that the relation subsisting between the maternal and fœtal placental surfaces and vessels in the human female is not that figured by Reid, Goodsir, Ecker, and others, I may state, that wherever I have had an opportunity of injecting the utero-placental area with the parts *in situ*—that is, with the placenta adhering to the mucous surface of the uterus—I have found an arrangement closely resembling in its general features that found in the mammalia as a class. It is only when the uterus and placenta are partially or altogether separated that the appearances described and figured are observed. In 1863 I destroyed and carefully injected a pregnant monkey, as being likely to throw additional light on this complicated and much disputed question. The monkey was near the parturient period, the fœtus being large and well formed. In the monkey the structure of the placenta remarkably accords with that found in man. In the present instance I injected the uterus, and then, having ascertained the site of the placenta within the uterus, I made an incision through the uterine wall at a considerable distance from it, through which I pulled the fœtus. I then injected the placenta from the umbilical vessels. The placenta consisted of a large oval isolated mass, which might have been taken for a human placenta at the sixth

[1] When the human chorion is shaggy, the placenta is diffuse, as in the mare; and this is a reason why even in its most matured condition, that is, in its concentrated and localised form, the human placenta is not to be regarded as a thing *per se*, but a modification of other placentæ, all of which are formed on a common plan. In the mare the villous tufts of the chorion are applied to the mucous lining of the uterus as a whole. In the tiger a band of villous tufts invest the chorion at its middle; the villi in this band only being applied to the mucous lining and capillaries of the uterus. In the ox the villous tufts of the chorion are grouped together, and appear as isolated patches, varying from an inch to an inch and a half in diameter. These form so many placentulæ. In the human female the villous tufts of the chorion are ultimately aggregated into one large oval mass, to which the name of placenta has been given. The human placenta is, so to speak, a concentration and higher development of all the other forms. Its great general features are however the same, and the manner of its application to the mucous lining and capillary vessels of the uterus in no respect differs from the others.

[2] See note 1, p. 487.

or seventh month. At a little distance from the placenta proper there was a placentula or little placenta, the vessels from which converged and united with the main vessels of the principal one. The placenta I regarded as an accidental formation. On making microscopical sections of the placental area, so as to embrace the maternal and fœtal vessels, their coverings, cells, glands, &c., the appearances observed were substantially those represented at Fig. 138, B; this figure, as already explained, embodying my views of the structure and physiological relations of the human placenta.

I am not, therefore, disposed to acquiesce in the commonly received opinion that in man the placental fœtal tufts are covered by an expansion of the corresponding vessels of the mother. I disagree—First, because there is no analogy to support this view. Second, because it is giving to the fœtus what I believe in reality belongs to the mother. Third, if the vessels of the mother are so expanded, they are necessarily destroyed when the placenta is removed, this relation involving the laceration and destruction of the mucous lining and capillary vessels corresponding to the maternal placental area—a proceeding which would expose the mother (notwithstanding the vigorous contraction of the uterus) to serious and probably fatal hæmorrhage. Fourth, that portion of the mucous lining of the uterus corresponding to the placental area is, as Dr. Matthews Duncan has shown, not removed in parturition. Fifth, in a healthy parturition there is almost no blood lost, a circumstance which could not occur if the arrangement figured by Reid, Goodsir, Ecker, and others obtained, as, in this case, not only large vessels, but large sinuses containing blood, would be exposed. Sixth, in the lower animals no blood is lost at parturition; but in these we know the maternal and fœtal capillary vessels or tufts are simply placed in apposition, the two separating with the utmost facility. Seventh, the blood-sinuses of the uterus (and by these I mean the maternal vascular expansions said to envelop the fœtal placental villi) are not necessary to gestation. That these sinuses are not necessary to the development of the fœtus is abundantly proved by this—that a fœtus (as in extra-uterine fœtation) can live and thrive where they do not exist. Eighth, I have never been able to detect a fœtal placental tuft or villus in a uterine maternal sinus (containing maternal blood), where the utero-placental relations were intact, that is, where the natural line of union between the maternal and fœtal portions of the placenta was inviolate. In such cases I have found an occasional fœtal villus in a utricular gland whose orifice was dilated; the uterine gland, as explained, opening on the free or mucous surface of the placental area. Ninth, and lastly, nothing is gained physiologically by the unnatural thinning and dilatation of the maternal vessels for the purpose of investing with bladder-like expansions the placental fœtal villi. A moment's reflection will show that such an arrangement would not bring the blood of the mother any closer to that of the fœtus than it would be if the maternal vessels remained unexpanded and normal. There are good grounds for believing that the placental villi (maternal and fœtal) simply fit into each other, and, by a process of interweaving and dovetailing, ultimately form a more or less solid mass. As the maternal and fœtal vessels by this arrangement are laid against each other in every conceivable attitude, a more perfect (and I will add a more extensive) osmotic action between the maternal and fœtal blood is induced than could otherwise be obtained. The osmotic action is favoured by the presence of a thin layer of utricular secretion between the maternal and fœtal villi and their appropriate coverings, as already explained.

The belief that the maternal uterine vessels do not expand to embrace the fœtal placental villi, as recorded by Reid, Goodsir, Ecker, and others, has been confirmed by the researches of Dr. Braxton Hicks, the President of the Obstetrical Society of London.[1] This gentleman argues against the existence of blood in the so-called maternal sinous system, and the sinous system itself, from finding that neither are present in extra-uterine fœtation. He inveighs against the presence of blood in the sinous system in normal pregnancy, as he can detect no trace of that fluid when the relations between the placenta and uterus are undisturbed. By the sinous system is here meant that space (or spaces) occurring between the fœtal villi of the chorion, which, according to commonly received opinions, is lined by the expanded uterine vessels of the mother. Dr. Hicks dissected four specimens. In two not a vestige of blood was found. In the others there was a vestige. In one of them the origin was clearly traced to a small clot extravasated among the villi; in that which remained, to a laceration of the villi themselves. Dr. Hicks adduces further evidence derived from three placentæ called "fatty." In these the decidual vessels were highly distended with blood, nevertheless the intervillal space was absolutely free.

So much for the vessels of the maternal portion of the placenta.

With regard to the vessels constituting the fœtal portion of the placenta (particularly their coverings), there is considerable diversity of opinion. Some say that the fœtal vessels and villi are bare; others that they are covered by a chorionic layer of cells; others that the chorionic cells are covered by a layer of decidual cells; others that in addition to all the foregoing there is a layer derived from the internal membrane of the vascular system of the mother.

[1] *Vide* Lancet for 18th May, 1872; also memoir by Dr. Robert Lee, "On the Structure of the Human Placenta and its Connection with the Uterus," *Phil. Trans.* 1832.

Dr. Arthur Farre holds that the blood of the fœtus is separated from the blood of the mother, first, by the walls of its own capillaries; second, by the gelatinous membrane in which these ramify; and third, by the external, non-vascular, nucleated sheath derived from the chorion. With the latter alone, he remarks, the blood of the mother is brought into contact.

There are, it will be observed, grave discrepancies in the explanations given both of the maternal and fœtal elements of the placenta; and I cannot help thinking that the truth will be evolved more readily if we discard a certain amount of detail and keep to general principles. Analogy, comparative anatomy, and development induce me to believe that the relation of the maternal to the fœtal portion of the placenta is not so complicated as authors have laboured to make it, and that the actual relation, as already explained, is that which one portion of skin or mucous lining, furnished with glands, capillary vessels, a limiting membrane, and epithelium, bears to another similarly constituted when the two are brought face to face and laid against each other.[1]

Not less conflicting are the views advanced as to the manner in which the fœtus is nourished and respires. Goodsir is of opinion that the fœtal placental villus consists of an external and internal membrane, each provided with nucleated secreting cells, and that between the two membranes there is a space which he regards as the cavity of a secreting follicle. The cells of the external membrane of the placental villus, according to him, secrete from the blood of the mother by means of the uterine capillaries the nutritive matter absorbed through the internal membrane by the internal cells, and conveyed thence to the fœtus by the fœtal placental tufts or villi. The secretion he compares to the cotyledonous milk of ruminants.

Ercolani advocates another view. He admits that the utricular glands do furnish materials for the nutrition of the embryo, but only in the early period of development; and he strives to prove that, from a transformation and greatly increased growth of the uterine mucous membrane, and of the sub-epithelial connective tissue, a new maternal glandular organ is produced, which in its simplest form consists of secreting follicles, arranged side by side and opening on the surface of the mucous membrane. In the human subject, he says, the typical form of the glandular organ is wanting, but the cells of the serotina, which invest the chorionic villi, represent the fundamental portions of the gland organ. Into these new-formed secreting follicles, and not into the utricular glands, the villi of the chorion penetrate, and are bathed by the fluid secretion, which they absorb for the nourishment of the fœtus.[2] Ercolani's hypothesis is ingenious, but there is no necessity for supposing that a new maternal glandular organ is formed, as existing structures very slightly modified can perform the work said to be performed by the new structure. Turner does not believe with Ercolani that the utricular glands cease to perform their functions at an early period of embryonic life. On the contrary, he states that in the Orca, "although the fœtus had reached an advanced state of development, the vascularity of the glands, their epithelial contents, even the presence of plugs of epithelium or inspissated secretion projecting through the orifices, all gave one the impression of structures in a state of active employment. If this be the case, then the secretion would be poured out into the crypts, and brought in contact with the villi of the chorion. . . . I am disposed, therefore," he adds, "to conclude that, in all these forms of placentation in which the utricular glands preserve their structural characters within the placental area, they play an important, if not the whole, part in the nutrition of the fœtus, not merely in the early,[3] but throughout the whole, period of uterine life."[4] Turner does not believe that the sub-epithelial corpuscles represented by himself (Fig. 146, *e*, *k*, p. 482) on the uterine and chorionic surfaces of the placenta, and which closely correspond to the external and internal cells of the placental villus of Goodsir (Fig. 142, *b*, *e*, p. 481), have a secreting function. He is inclined to regard them as lymphoid bodies which have wandered out of the adjacent capillaries into the connective tissue, to whose nutrition and growth they administer.

According to Goodsir, as has been explained, "the external cells of the fœtal placental villi perform, during intra-uterine existence, a function for which is substituted in extra-uterine life the digestive action of the gastro-intestinal mucous membrane. The internal cells of the fœtal placental villi perform during intra-uterine existence

[1] See a curious case of "a placenta partially adherent to a nævus occupying the scalp and dura mater." (Lond. Med. Chir. Soc. Trans., xxii. 1829, pp. 300–309.)

[2] Ercolani, as rendered by Turner, in his memoir "On the Gravid Uterus, and on the Arrangement of the Fœtal Membranes in the Cetacea (*Orca gladiator*)." (*Trans. Roy. Soc. Edin.*, vol. xxvi. p. 500, 1871.)

[3] "When the ovum, with its villous chorion, reaches the uterus, the villi become embedded in the secretion poured forth by the enlarged follicular glands of the mucous membrane of that organ; and from this they doubtless derive the nutriment on which the embryo at first subsists. . . . Coincidently with the increasing size of the follicles, the quantity of their secretion is augmented, the vessels of the mucous membrane become larger and more numerous, while a substance composed chiefly of nucleated cells fills up the intra-follicular spaces, in which the blood-vessels are contained. The object of this increased development seems to be the production of nutritive materials for the ovum; for the cavity of the uterus shortly becomes filled with secreted fluid, consisting almost entirely of nucleated cells, in which the villi of the chorion are embedded. . . . After impregnation the glands of those parts of the mucous membrane which come into immediate relation with the ovum greatly enlarge, while the extremity of each compound gland, just before it opens on the surface of the uterus, dilates into a pouch or cell, filled with whitish secretion, within which is received a process of the chorion." ("Kirkes' Physiology," 3rd ed. 1856.)

[4] "On the Gravid Uterus, and on the Arrangement of the Fœtal Membranes in the Catacea (*Orca gladiator*)." (*Trans. Roy. Soc. Edin.*, 1871, pp. 501, 502.)

a function for which is substituted in extra-uterine life the action of the absorbing chyle-cells of the intestinal villi. The placenta, therefore, not only performs, as has been always admitted, the function of a lung, but also the function of an intestinal tube." [1] Dr. John Reid, as has been pointed out, believed that the uterine capillary vessels expanded to such an extent that they invested the fœtal capillary tufts (Fig. 144, *d*, p. 481), the fœtal villi being bathed by the blood of the mother much in the same way that the gills of aquatic reptiles are bathed by water. The placenta, Dr. Reid observes,[2] is therefore not analogous in structure to the lungs, but to the branchial apparatus of certain aquatic animals.[3] If the views suggested in the text, and illustrated by Fig. 138, B (p. 479), and Fig. 157 (p. 485), be adopted, the opinions of Goodsir, Reid, Ecker, Ercolani, Turner, and others, may readily be reconciled, as the utricular glands secrete a fluid which assists in nourishing the fœtus, while it at the same time acts as an osmotic medium. The membranes and cells found on the surfaces of the maternal and fœtal portions of the placenta secrete, by a double process, from the capillaries (maternal and fœtal) which they cover, the substances necessary to the well-being alike of parent and child—the placental membranes and utricular glands working together. The placental membranes and cells, as I have shown, enclose a space which, from the fact of the glands pouring their secretion into it, I designate the "*utricular space.*" The space in question contains the utricular secretion or cotyledonous milk. To this cotyledonous fluid I am disposed to attach considerable importance, as it is one of the sources from which the fœtus derives its nourishment in the early months of pregnancy, before its blood-vessels are formed, and the medium through which the blood of the mother operates on the blood of the fœtus and *vice versâ*, when the maternal and fœtal villi are fully developed. In short, I regard the utricular space, with its glandular secretion, as performing at once the office of a stomach, a lung, and an *osmotic medium.*

The capillary blood-vessels of the mother and fœtus are entirely distinct, and separated, as has been stated, by two membranes and two sets of cells. Here we have the conditions necessary for a vigorous osmotic action. Both sets of vessels contain blood, but, as the blood of the mother and fœtus are very similarly constituted, they can only act upon each other when a third and thicker fluid is present, on the principle "ex nihilo nihil fit." This thicker fluid the utricular glands supply. It is the thinner portions of the maternal and fœtal blood which flow out of the vessels by a process of endosmose into the utricular space, where they commingle; part of the mixed fluid returning by a process of exosmose to the vessels alike of the mother and fœtus. By this means a free interchange of nutritious and effete matters is permitted, the mother and fœtus participating equally. This would account for the influence exerted by the mother on the fœtus, and the converse; the fœtus, as is well known, altering the constitution of the mother, and affecting even her future progeny.[4] The fœtal and maternal vessels abut against each other in every conceivable position, and as they are only separated from one another by an osmotic medium and certain membranes and cells, the maternal and fœtal blood yield up their peculiar ingredients to each other; gases (especially when in a state of solution), like fluids, readily passing through certain membranes. The blood of the fœtus, there is reason to believe, is by this means nearly as well aërated as the blood of the mother.

The details and "means to ends" witnessed in the fixing of the embryo and fœtus to the interior of the uterus, the formation of the placenta, the blending of the vital and physical forces during development in varying degrees to meet the requirements of each particular case, the mode of nourishing and aërating the blood of the fœtus by that of the mother, the separation of the fœtus and the mother at full time, and the provision made for the terrestrial life of the fœtus after parturition, to say nothing of other and notable changes, such as the terrestrial respiration of the infant and the production of milk in the mammæ of the mother, are such as can only be explained by a First Cause, design, and supervision. The several changes referred to cannot be accounted for by chance or the inherent irritability of the parts in which the changes occur. Neither can they be referred to environment, which, in this case, is permanent, all else being fluctuating. Impregnation, gestation, and parturition are naturally parts of the same thing, and are traceable to a common source; that source embracing all the vicissitudes of embryonic and fœtal life in their relation to the mother and the cycle of changes which occur in her. There is a double life in the

[1] "Anatomical and Pathological Observations," by John Goodsir, Esq., F.R.S.E. &c.; Edin. 1845, p. 63.

[2] "Physiological, Pathological, and Anatomical Researches," by Dr. John Reid, 1848, p. 327. Reid's paper "On the Blood-vessels of the Mother and Fœtus (Human)" originally appeared in the *Edin. Med. and Surg. Journal* (No. 146) for January 1841.

[3] If this analogy be admitted, the following difference is to be noted:—The branchiæ of the aquatic reptile are in the immediate vicinity of the heart, whereas the placenta is widely removed, not only from the heart, but even the body of the fœtus. In this sense the placenta is outside and beyond the fœtus; hence the necessity for that remarkable system of canals which constitute the umbilical cord. This cord might be of any length, it being a mere tunnel to enable the circulation of the fœtus and mother to reciprocate. Similar remarks may be made regarding the principal arteries and veins of all the higher animals. The really effective circulation occurs within the capillaries and tissues, and the large vessels stand in the same relation to the heart as aqueducts to their reservoirs. The longest vessels of all are to be found in trees. The umbilical cord consists of two arteries and one vein; but it is not to be inferred from this that the arteries and their radicles contain arterial blood, and the vein and its radicles venous blood. On the contrary, the vein contains arterial blood, and the arteries mixed blood.

[4] When a white mother bears a child to a black father, the future offspring, even if begotten by a white father, may be coloured. John Hunter relates a curious case of an English mare covered by a quagga horse. The offspring displayed the quagga stripes, and these stripes reappeared in the future progeny of the mare when put to English horses.

mother and child, and the changes which occur in the one are accompanied by similar and sympathetic changes occurring in the other. Not only is a First Cause necessary for the production of the elaborated, highly-complicated machinery of gestation, but continued supervision by the First Cause becomes a *sine quâ non*. In the arrangements under consideration, design meets us at every turn, and the more closely these are examined the more wonderful they become. These arrangements are, from the nature of the case, predetermined. They are original, and not mere modifications of any pre-existing ones. They are not due to natural selection. Each plant and animal only produces its kind, and the "ways and means" are in each particular case to all intents and purposes identical. That countless millions of plants and animals should repeat themselves and persist—in other words, should remain constant to their original types—is one of those stupendous organic puzzles which still await solution. The prevailing forms of plants and animals are not, as many believe, produced by modifications extending through untold ages of ancient and modern time. The persistency of plants and animals on the earth in a practically unchanged form since the dawn of creation effectually disposes of this hypothesis. Neither are they the produce of one plant or animal out of another plant or animal which preceded it. The most probable explanation is that plants and animals are separate creations founded on a general plan; each plant and animal forming a persistent type which is at no time departed from. Given the types, slight variations within limits are permissible—the variations, when they do occur, being corrected soon after their appearance by a strongly-marked tendency to revert or breed back to their originals. The latter remark applies equally to both plants and animals.

I have described at length the peculiarities of the fœtal circulation, and have explained that two kinds of forces are employed, namely, the visible and invisible—the visible forces carrying on the circulation within the body of the fœtus, the invisible forces carrying on the circulation within the placenta. In what follows I occupy myself solely with the visible forces, and with the machinery, if I may so phrase it, in which the visible forces manifest themselves, namely, the heart, blood-vessels, nerves, &c. A consideration of the visible forces necessarily involves details; but I shall strive to put them in such a way as not to prove irksome. Hitherto we have been dealing with the machinery of the circulation as a whole, now it behoves us to become acquainted with the different parts of that machinery. In describing the several structures employed, I must ask the forbearance of the reader, if at times I repeat myself. I only do so because nature repeats herself, and because, in dealing with the highest form of the circulation as it exists in the bird and mammal, I am necessarily dealing with essentially the same materials and forces employed in the lowest. It is this circumstance which makes the comparative anatomy and physiology of the circulation laborious and long; but the same circumstance, it appears to me, imparts to the circulation, as it exists in ourselves, its chief interest.

In my remarks on the fœtal circulation, I directed attention to the fact that the cavities of the heart of the fœtus open into each other—the two auricles communicating directly by the foramen ovale, the two ventricles communicating indirectly by a canal extending between their great vessels, namely, the ductus arteriosus. On a previous occasion I stated that a somewhat similar arrangement obtains in the reptile, where the two auricles open into a single ventricle—this ventricle, in certain cases, being partially divided into two by a rudimentary septum ventriculorum. The circulation in the fœtus and reptile is from this circumstance a mixed circulation, that is, the blood circulated is partly arterial and partly venous. The reptiles are cold-blooded animals; and the fœtus might be classed under this heading also, were it not for the fact that the blood of the fœtus is of the same temperature as that of the mother. To obtain a warm blood, such as is found in the bird and mammal, the chambers of the heart must be walled off from each other, and thus it is that in birds and mammals the cavities of the right and left halves of the heart do not intercommunicate. A warm blood is the result of a complete arterialisation, and this can only be produced where the lungs and breathing apparatus are sufficiently differentiated, and when a complete pulmonic and systemic heart are present. I use the term "breathing apparatus" in its widest sense, for we know that the tissues respire, and that the blood is always warmest where its oxidation goes on most vigorously.[1] That the differentiation of the heart into four distinct chambers has something to do with maintaining the blood at a certain temperature is proved by this—that in morbus ceruleus, where the cavities of the heart communicate abnormally, the temperature of the body is very considerably reduced. The temperature of the blood bears a fixed relation to the activity of respiration; the respiratory power and temperature being highest in birds, then in mammals, then in reptiles and fishes, and lastly in the invertebrata.[2] Mr. Newport has pointed out the very

[1] Sir Benjamin Brodie, in the Croonian Lecture for 1810, and in the Philosophical Transactions for 1812, cited experiments to show that the maintenance of animal temperature is directly or indirectly under the influence of the nervous system.

[2] In birds, according to Tiedmann and Rudolphi, the average temperature is 107°; the temperature in the linnet rising to 111·25°. In mammalia the average temperature is 101°; in the bat (*Vespertilio pipistrella*) 106°; in the narwhal 96°. In reptiles it is 82·5°, when the surrounding medium is 75°. In fish (the tunny tribe excepted) and in the invertebrata it is the same as the medium in which they live. The mammalia and birds, as Mr. Hunter ascertained, have a certain permanent heat in all atmospheres, while the temperature of the others is variable with every atmosphere.

interesting fact that the larvæ of insects with small respiring organs have a lower temperature than the perfect insect; and that the flying insects, because of their possessing a large respiratory apparatus, have a higher temperature than the non-volant ones. During sleep and hibernation the respiration and temperature decrease.

§ 130. Distribution of the Great Vessels in Reptiles, Birds, and Mammals.

I have alluded to the general distribution of the vessels proceeding from the ventricle or ventricles, as the case may be, of the reptile, and it is important that I should now direct attention to their arrangement in the heart of the bird, and to the construction of the descending aorta, as this forms one of the connecting links between the circulation in birds and reptiles on the one hand, and birds and mammals on the other. The aorta of birds is very short, and divides into three principal branches almost before it leaves the left ventricle (Fig. 161, *a*, *b*, *c*). The aorta of birds arches in the direction of the right bronchus; whereas in mammals it arches towards the left bronchus. (Compare *b* of Fig. 161 with *u* of Fig. 162.) Of the three branches of the aorta in birds, one arches towards the right axilla, and the other to the left, these being analogous to the single arteria innominata of man, the birds having virtually two innominates. The pulmonary artery of birds divides into two branches as in the mammal, one going to the right lung, the other to the left (Fig. 161, *d*; compare with *v* of Fig. 162).

In all reptiles the descending aorta is formed by the union of two branches—the right and left aortic branches. The right corresponds with the systemic aorta of birds, and arises from the left ventricular compartment. The left arch leads generally from the right ventricular cavity into the descending aorta, and joins the right arch towards the back. The number and distribution of the great vessels proceeding from the heart become fewer and less complicated in the mammal. Here the great vessels are reduced to two; the aorta proceeding from the left ventricle and giving off the innominate, left carotid, and left subclavian arteries, which in conjunction with the descending aorta and branches, convey arterial blood to all parts of the system; and the pulmonary artery, arising from the right ventricle, which sends blood exclusively to the lungs. Although the great vessels of the mammalian and human heart are reduced to two, it is worthy of remark that the tendency to an arched or branchial arrangement distinctly recurs. Thus the aorta and pulmonary artery are plaited upon each other, the aorta arching from right to left; the pulmonary artery subdividing and arching equally to right and left (Fig. 162).

FIG. 161.—Anterior aspect of turkey's heart, with right and left ventricles opened to show auriculo-ventricular valves. *a*, Aorta arching to right side and dividing into three branches, two of which (*b*) go to right side, and one (*c*) to left side; *d*, pulmonary artery dividing into two, and sending a branch to right and left lungs; *i*, muscular or fleshy valve which occludes right auriculo-ventricular orifice; *j*, musculus papillaris of fleshy valve (compare with *g*); *e*, portion of septum to which valve is applied when closed; *f*, left ventricle; *v*, tendinous valve which occludes left auriculo-ventricular orifice; *g*, musculus papillaris with chordæ tendinæ attached to tendinous valve. (The Author, 1864.)

FIG. 162.—Shows the distribution of the great vessels at the base of the human heart, seen anteriorly. Contrast with Fig. 161. *u*, Aorta giving off innominate, left carotid, and left subclavian arteries; *m*, descending aorta; *v*, pulmonary artery dividing and giving branches to right (p') and left (p) lungs; *a*, trachea bifurcating and dividing in right (p') and left (p) lungs; *y*, descending cava; *o*, ascending cava; *s*, right auricle; *q*, right ventricle; *t*, left auricle; *r*, left ventricle.

In birds and reptiles there are two superior cavæ, a similar number being found in the mammalia which approach nearest to the oviparous vertebrata, as the monotremata and marsupiata, and in some of the rodentia, as for example the porcupine. The heart of the bird, like that of the mammal, consists of four distinct cavities, the cavities being separated from each other by valves and muscular partitions; the former occurring in the auriculo-ventricular orifices, and isolating the right and left auricles from the right and left ventricles; the latter separating the right auricle from the left auricle, and the right ventricle from the left ventricle. The right auricle of the bird is comparatively very large, and the right ventricle highly differentiated, it being supplied with a wonderfully perfect muscular valve which I carefully described in 1858 (Fig. 161, *i*). It takes the place of the tricuspid valve in mammals (Fig. 164, *f*, p. 499). The elaboration of the right heart of the bird is, no doubt, connected with the very perfect and very extensive respiration of that animal.

§ 131. Valves in the Heart of the Bird.

The system of valves in the heart of the bird is very complicated and very complete. The inferior cava is guarded at its orifice by a semilunar valvular fold, which separates it from the orifice of the left superior cava. The

orifices of the inferior and left superior cavæ are further protected by the large valves which guard the mouth of the coronary sinus. "In the emu a strong oblique semilunar *muscular fold* commences by a band of muscular fibres running along the upper part of the auricle, and, expanding into a valvular form, extends along the posterior and left side of the sinus, terminating at the lower part of the fossa ovalis. A second semilunar *muscular valve* of equal size extends parallel with the preceding along the anterior border of the orifice of the sinus, its lower extremity being fixed to the smooth floor of the auricle, its upper extremity being continued into a strong muscular column running parallel to the one first mentioned across the upper and anterior part of the auricle, and giving off from its sides the greater part of the musculi pectinati." [1]

The other valves of the bird's heart—namely, the aortic, pulmonic, and mitral (Fig. 161, *v*, p. 493)—closely resemble those of the mammal, a description of which will be given further on. The aortic and pulmonic valves of the bird consist of three semilunar cusps or segments—the valves which occupy a similar position in the reptiles having only two cusps. The remarkable feature in the valves of the heart of the bird consists in the amount of muscular fibres mixed up with their tendinous and fibrous tissues, some being partly, and others wholly, muscular.

§ 132. The Respiration and Circulation in Birds.

The differentiation perceptible in the cardiac valves of the bird is necessitated by the highly developed condition of the lungs, the lungs being more capacious than in any other class. The increased capacity of the lungs becomes a *sine quâ non* when it is remembered that birds require to make great exertions in launching themselves into the air from a level surface, and also in diving. A bird exerts its greatest power in rising. When fairly launched in space the weight of its body acts upon the twisted inclined planes formed by the wings, and does the principal part of the work.[2] The air cells and spaces in birds extend in many cases to every part of the body, not excepting the bones [3] and muscles; and a bird can respire for a short time after the trachea is closed if the humerus be perforated. The great air-sacs in connection with the lungs of birds, as I have ascertained from artificial injections, have arteries and veins in considerable numbers ramifying on their surface, the arterial and venous blood contained in the vessels being equally exposed to the influence of the air within the air-sacs. The air-sacs, which are apparently mere appendages of the lungs, are in reality the harbingers and types of all lungs. They closely resemble, in their rudimentary form, the hollow viscera of vertebrates.[4] The fish has its swimming bladder—a closed sac containing air instead of urine, but which, like the urinary bladder, can open and close. "In the water-newt, the lungs consist of a pair of elongated sacs, without any internal laminæ or folds. In the frogs these membranous sacs present ridges on their inner surface, especially at the upper part; and in the lungs of the turtle and crocodile these ridges increase in number and in size, and form partitions dividing the interior of the lungs into numerous cells communicating with each other." The differentiation is carried still further in the bird and mammal; and there are grounds for believing that these, like the more simple air-bladder of the fish, have the power of opening and closing within certain limits.

§ 133. The Air-sacs of Birds, &c.

The air-sacs of birds have nothing whatever to do with flight, as they are found in birds which do not fly, and flight can be performed by the bat in their absence. Sappey enumerates as many as fifteen air-sacs. They open the one into the other, and as they have a peristaltic action, currents of air are continually passed throughout the entire substance of the body, very much as in the tracheæ of insects and in the older vascular bundles of plants. The peristaltic movements of the air-sacs of birds show the intimate relation existing between the lungs and the heart; the one circulating air, the other blood. The air-sacs of birds were described by John Hunter as early as 1774. Somewhat analogous membranous expansions are found in connection with the lungs of serpents—the

[1] "Comparative Anatomy and Physiology of Vertebrates," by Professor Owen.

[2] "On the Mechanical Appliances by which Flight is attained in the Animal Kingdom," by the Author (Trans. Lin. Soc., vol. xxvi.). "On the Physiology of Wings," by the Auth(or *Trans. Roy. Soc. Edin.*, vol. xxvi.).

[3] "In the gannet and pelican the air enters all the bones with the exception of the phalanges of the toes, and in the hornbill even these are permeated by air." ("Comp. Anat. and Phys. of Vertebrates," by Professor Owen, vol. ii. p. 214.)

[4] "In all the air-breathing vertebrata the respiratory membrane is formed by a prolongation of the internal tegumentary or mucous membrane from the upper part of *the digestive tube*; and this also holds true in the aquatic vertebrata and the fishes. When the expanded respiratory membrane is placed at some distance from that portion of the mucous membrane of the digestive tube with which it is continuous, as is especially the case in mammalia and birds, this mucous membrane is prolonged to the part where its expansion occurs, in the form of a tube strengthened on the outer surface by elastic textures, to enable it to withstand the atmospheric pressure. Along this tube (trachea) and its branches (bronchi and bronchial tubes) the air passes to and from the proper respiratory membrane on the inner surface of the lungs." (Cyc. of Anat. and Phys., "Arterial Respiration," vol. iv. p. 331.)

python, for example; so that the lungs of birds, which represent the highest development of pulmonary organs, have certain affinities with the lungs of reptiles, which are not differentiated to anything like the same extent.

The only peculiarities in the circulation of birds to which allusion is necessary are to be found in a modification of the portal circulation and the possession of a distinct renal circulation. The veins of birds anastomose very freely. One of these anastomosing branches extends between the united caudal, hæmorrhoidal, and iliac veins to the vena porta, so that the blood from the viscera and posterior part of the body flows either into the vena porta or vena cava inferior. The renal circulation of birds was discovered by Professor Jacobson. It is venous in character, branches of the inferior cava proceeding to the interior of the kidneys.[1] Other investigators have found what virtually amounts to a renal circulation in reptiles and fishes.

THE CIRCULATION IN THE MAMMAL

My description of the heart of the bird applies, with slight modifications, to the heart of the mammal. This, too, consists of four distinct cavities—two auricles and two ventricles; the auricles and ventricles in the adult being separated from each other by valves and by muscular partitions or septa. In virtue of this arrangement the heart of the mammal is often spoken of as consisting of a right or pulmonic heart composed of the right auricle and right ventricle, and a left or systemic heart composed of the left auricle and the left ventricle. The terms pulmonic and systemic have been employed because the right heart receives the impure venous blood from the system and forces it into the lungs; the left heart receiving the pure arterial blood from the lungs and forcing it into the system. This arrangement provides for what may be regarded as a distinct venous circulation, and a distinct arterial circulation; the two kinds of blood, namely, the arterial and the venous, being no longer mixed either in the vessels or in the heart (Fig. 162, p. 493).

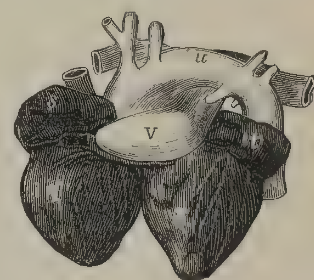


FIG. 163.—Heart of dugong seen anteriorly; shows bifid apex. *s*, Right auricle; *q*, right ventricle; *t*, left auricle; *r*, left ventricle; *u*, aorta giving off innominates, left carotid and left subclavian arteries; *v*, pulmonary artery bifurcating and proceeding to right and left lungs. Compare with human heart, Fig. 162, p. 493 (Owen).

In the dugong, the systemic and pulmonic hearts are very distinct—the right and left ventricles being widely separated from each other at their apices, and only joined towards their bases, as shown at Fig. 163. This virtually divides the organ into a left or systemic, and a right or pulmonic heart. The auricles of the heart of the dugong are of equal size, and the ventricles closely resemble each other in their general configuration. The heart of the whales and dolphins more closely resembles that of the other mammals. The arteries of the whale, as John Hunter pointed out, are remarkable for their tortuosity and convoluted arrangement. Vast plexuses of tortuous vessels are found under the pleura and between the ribs and their muscles on each side of the spine. Similar plexuses surround the medulla spinalis, more especially where it comes out from the brain. In the porpoise the veins, which are for the most part devoid of valves, display a similar tortuosity, particularly on either side of the spine below the kidneys. When artificially injected the venous plexuses present a very unusual appearance.[2] Hunter was of opinion that the cetacea contain more blood in proportion to their size than other mammals; and the vast arterial and venous expansions referred to certainly favour this view. He thought the expansions had something to do with the habits of the animals—the cetacea remaining submerged for long intervals, and devoting very short periods to breathing and aërating their blood. He thought, in fact, that the plexuses acted as reservoirs for oxygenated blood, and prevented asphyxia when the animals dived. This may form a partial, but is not the whole explanation, as I have succeeded in injecting similar arterial and venous plexuses in the arms and legs of the sloth, the arms, legs, and tail of the spider-monkey, and the testicles of the ram—where, of course, no such aggregation of oxygenated blood is required.[3] Sir Charles Bell believed that the plexuses and increased vascular supply were necessary to parts performing a large amount of work, or undergoing strain; such parts requiring a more liberal supply of nutritive material. The tortuosity of the vessels quite explains the absence of valves in the veins; the plexuses of veins in the porpoise resembling varicose veins in ourselves, where the valves are diseased or broken down. The circulation in the cetacea is especially remarkable for its magnitude. The enthusiastic and justly-renowned Hunter found in the circulation of the cetacea a subject worthy of his scalpel. He says—"In our examination of particular parts, the size of which is generally regulated by that of the whole animal, if we have only been accustomed to see them in those which are small or

[1] I have had opportunities of injecting the kidneys of birds, and the degree of vascularity is in some cases quite remarkable.
[2] In illustration, see specimens injected and prepared by me, deposited in the Museum of the Royal College of Surgeons of England, London.
[3] These preparations are deposited in the Hunterian Museum of the Royal College of Surgeons of England, London, where they may be consulted.

middle-sized, we behold them with astonishment in animals so far exceeding the common bulk as the whale. Thus the heart and aorta of the spermaceti whale appeared to be prodigious, being too large to be contained in a wide tub, the aorta measuring a foot in diameter. When we consider these as applied to the circulation, and figure to ourselves that probably ten or fifteen gallons of blood are thrown out at one stroke, and moved with an immense velocity through a tube of a foot diameter, the whole area fills the mind with wonder." [1]

In order, as it were, to make the differentiation between the systemic and pulmonic circulation more obvious, the systemic circulation is carried on within vessels termed arteries, and the venous circulation within vessels termed veins. These are separated from each other at the periphery of the body and the organs thereof, by minute plexuses of vessels, which, from their small size, are denominated capillaries. They are separated at the heart by muscular and valvular septa. The arteries begin at the heart and terminate at the capillaries; the veins begin at the capillaries and terminate at the heart. Between and around the capillaries, a very minute system of vessels, the hyper-vascular canals, are found. The arteries break up, branch or bifurcate, and become smaller and smaller as they become more distant from the heart; the veins, on the other hand, converge and unite, and become larger as they near the heart.

The arterial and venous systems may not inaptly be compared to a cone, the apex of which is directed towards the heart; or to a tree, which bifurcates near its roots, and whose stem and spreading branches represent the arterial and venous vessels lying side by side. The arterial system is in some respects the converse of the venous. The arteries have thick walls, are elastic in the direction of their length and breadth, and, if the aortic semilunar valve be excepted, are not furnished with valves. They are also comparatively narrow. The veins have thin walls, are less elastic than the arteries, and are provided with numerous valves which may consist of from one to four or more segments. The veins are, comparatively speaking, very wide. The presence of valves in the veins and other structures is to ensure that the circulating fluid shall always proceed in one direction. They are the sluices or floodgates which are thrown open by the advancing tide, but which are closed the instant it attempts to retrogress or recede.[2]

With the peculiarities of the circulation in the mammal most readers are familiar. I will, however, take the liberty of briefly adducing the leading facts connected with it, as an enumeration of these will enable me to introduce some new matter which may prove interesting.

§ 134. The Auricles, Ventricles, Valves, Septa, &c., of the Heart of the Mammal.

The mammalian heart (of which the human may be taken as an example) is a conical-shaped, hollow, muscular mass, slightly twisted upon itself, particularly at the apex.[3] It is divided into four distinct compartments—a right auricle and a right ventricle, and a left auricle and a left ventricle. The right auricle is separated from the left auricle by a muscular partition, a similar partition running between the right and left ventricles. The right and left auricles are separated from the right and left ventricles by valvular septa (the mitral and tricuspid valves), which, when the auricles and ventricles alternately open and close, rise and fall like diaphragms (Figs. 164, *f*; 165, *m*, *i*, *n*; p. 499). The cavities of the heart are of nearly the same size, the walls of the right auricle being so thin in parts as to be nearly transparent. Those of the left auricle are a little thicker. The walls of the right ventricle are about twice the thickness of those of the right auricle; while those of the left ventricle and septum are nearly twice as thick as those of the right ventricle. The thickness of the walls of the auricles and ventricles is in exact proportion to the work to be performed by them—the left ventricle having a greater amount of work to do than the right ventricle, and the left auricle than the right. This is proved by the fact that in the fœtus, where there is no distinct pulmonic and systemic circulation, the walls of the ventricles, until quite towards the full term, are of nearly the same thickness. It is also proved by hypertrophy of the right ventricle in cases of disease of the lungs, which, obstructing the passage of the blood through the pulmonic vessels, necessitates an increase of power in the propelling organ. In order to understand the course pursued by the blood in the right or pulmonic, and the left or systemic heart of the mammal, it is necessary to be familiar with its entrances and exits.

[1] *Phil. Trans.*, 1787, p. 415.

[2] "In man the valves are very numerous in the veins of the extremities, especially the lower ones, these vessels having to support the blood against the force of gravity. They are absent in the very small veins, also in the venæ cavæ, the hepatic vein, portal vein and its branches, the renal, uterine, and ovarian veins. A few valves are found in the spermatic veins, and one also at their point of junction with the renal vein and inferior cava in both sexes. The cerebral and spinal veins, the veins of the cancellated tissue of bone, the pulmonary veins, and the umbilical vein and its branches, are also destitute of valves. They are occasionally found, few in number, in the venæ azygos and intercostal veins." ("Anatomy, Descriptive and Surgical," by Henry Gray, Esq., F.R.S., &c., p. 401.)

[3] In mammalian hearts the apex is slightly notched, the notch varying in different animals. In the dugong it is so deep as to separate the right and left ventricles throughout half their extent. The notch in question forms the boundary between the apices of the right and left ventricles (Fig. 163, p. 495).

§ 135. The Right Heart of the Mammal.

The blood enters the right auricle by two principal openings: the one communicating with the superior cava, through which it receives the venous blood from the head and upper extremities; the other communicating with the inferior cava, through which it receives the venous blood from the trunk and lower extremities (Fig. 164, *a*, *b*). These openings are not provided with valves, so that the reflux of the blood when the right auricle closes is prevented in part by atmospheric pressure, by the closing of the valves of the large veins of the upper extremities and neck, and in part by the closure of the cavæ themselves, which are supplied with muscular fibres for this purpose. In addition to the openings of the superior and inferior cavæ, there are those of the coronary sinus and foramina Thebesii, through which the venous blood of the heart itself finds its way into the right auricle. These constitute the entrances into the right auricle. There is only one exit. The venous blood passes from the right auricle into the right ventricle by the right auriculo-ventricular orifice, which is guarded by the tricuspid valve (*f*). Once in the right ventricle, the blood is expelled through the funnel-shaped canal known as the infundibulum or conus arteriosus into the pulmonary artery (*d*), the orifice of which is guarded by the pulmonic semilunar valve (*h*). It thence finds its way into the lungs, where it is oxygenated; and there we leave it for the present. The right auricle and right ventricle form a through route for the venous blood, this being collected in the right auricle, which, when it closes, forces it into the right ventricle, the right ventricle in turn forcing it into the lungs (*vide* arrows of Fig. 164).

§ 136. The Blood urged on by a Wave-Movement; the Heart and Vessels Open and Close in Parts.

The blood is projected by a progressive wave-movement, which begins in the cavæ and extends to the right auricle, and thence to the right ventricle; the right auricle opening as the two cavæ close, and the right ventricle opening as the right auricle closes. The blood is thus forced on by a *vis a tergo*, aided by a sucking or *vis a fronte*, movement. The *vis a tergo* or closing movement acts in conjunction with the elasticity of the vessels; the *vis a fronte* or sucking movement in conjunction with atmospheric pressure and the demand set up by the tissues for nourishment. If the different parts of the heart have the power of expelling their contents, they should, *ceteris paribus*, have the power of opening to receive a new supply. Dr. Carson believed that the different parts of the heart relaxed after being contracted; the relaxation being favoured by the distribution of the muscular fibres, by the elasticity of the lungs, and by a diminution of atmospheric pressure on the *outer or convex surface* of the heart, the pressure of blood on the great veins which conduct to the organ, and which act on its *inner or concave surface*, being increased. In other words, he was of opinion that the relation between the lungs, pleura, heart, and pericardium was such, that the different parts of the organ were opened in a great measure mechanically by a simultaneous withdrawal and increase of atmospheric pressure on its outer and inner surfaces.[1] While agreeing with Dr. Carson that the heart exerts a pulling and pushing power, I differ from him as to the *modus operandi*. In short, I attribute the opening and closing powers possessed by the different parts of the heart to an inherent vital power. That the movements in question are not due to a rhythmic pressure exerted outside and inside the organ is obvious from this, that the heart acts when it is cut out of the body and deprived of blood, the atmospheric pressure on its outer and inner surfaces being equal. That the heart regulates its movements irrespective of atmospheric pressure is further apparent from the fact that its different parts move at different times—the hearts of some of the lower animals, by the mere vermicular movements of their walls, transmitting two kinds of blood through a single chamber. Thus Goodsir[2] observed that there is a slight asynchronism between the movements of the right and left auricles in the heart of the lizard,[3] and that the contraction of the ventricle begins at its right side, in the neighbourhood of the pulmonary artery, and terminates at the left or arterial sinus of the ventricle. Brücke, in his memoir in the Vienna Transactions, has, curiously enough, described a ventricular arrangement by which venous blood only passes into the pulmonary artery in reptiles; the ventricle beginning to contract on the right side, and afterwards on the left.

Many are of opinion that the closing of the auricle produces the opening of the ventricle, the closing of the ventricle in turn dilating the auricle. This would be a mere waste of power; and, besides, unless the ventricle opened spontaneously, the blood from the auricle, which is the distending medium, would be denied admission. The ventricle when it closes becomes a solid mass, to which no fluid, however great the pressure exerted by it, can gain access (Plate lxxxv., Fig. 2, p. 325).[4] Nor must it be overlooked that occasionally, when the heart is acting

[1] "An Enquiry into the Causes of the Motion of the Blood," by James Carson, M.D., 1815.
[2] "Anatomical Memoirs," vol. i. p. 443.
[3] Similar asynchronism was observed in the auricles of the turtle and frog.
[4] In discharging my duties as Pathologist to the Royal Infirmary of Edinburgh (1870–75), I occasionally opened hearts, the ventricular cavities of which were quite obliterated. The extent of centripetal or closing power possessed by the hollow viscera is very remarkable. I have at present in my possession a human stomach, the calibre of the body of which is not greater than that of the small intestine. The patient died of starvation, induced by cancer of the œsophagus.

slowly, the ventricle opens before the auricle closes, and the converse. Furthermore, the several parts of the heart open and close when cut out of the body and deprived of blood. There is, therefore, no sufficient ground for believing that the opening of the ventricle is due to the closing of the auricle, and *vice versâ*. On the contrary, observation and experiment tend to prove that the different compartments of the heart open and close spontaneously by vital and independent acts. The probabilities are, that there is no such thing as a violent closing of one part of the circulatory apparatus producing a violent opening of another part.[1] That the different parts of the heart and vessels are endowed with the power of opening and closing is in great measure proved by this, that in the lower animals, where there are no hearts, the vessels pulsate and carry on the circulation by themselves. Similar pulsating vessels, as has been already explained, are found when hearts are present; as in the mesenteric vessels of the frog, the veins of the bat's wing, the caudal vessels of the tail of the eel, the saphenous veins of the rabbit; and the chances are, that the vessels generally perform an important part in the visible circulation of vertebrates.[2] The caudal vessels of the eel display a circulation which may be regarded as a venous heart. The power of the vessels to open and close in parts decreases as the elastic properties of the vessels increase. The inferior vena cava, the renal, azygos, and external iliac veins, and the large trunks of the portal venous system and hepatic veins, as Dr. Gray has shown, contain longitudinal and circular non-striated muscular fibres, so that they have a structure resembling that of the intestine, the power of which to transmit solid, semi-solid, or fluid contents is well known. In addition, the inferior cava and the pulmonary artery and aorta at their origins are abundantly supplied with nerves—an arrangement which assimilates the great vessels situated at the root of the heart to the bulbus arteriosus of fishes, which, as has been shown, is endowed with rhythmic power. The vessels aid the circulation indirectly by their elasticity and resiliency. By receiving and storing up part of the impulse communicated to the blood by the closing of the ventricles at each systole, and by expending the power thus imparted gradually between the pulsations, they tend to equalise the current, and give continuity of movement. That the calibre of the great vessels increases when the ventricles close is proved by placing a ring of metal with a slit in it round the carotid of the horse or other large animal. The slit is widened during the closing of the ventricles or systole, and diminished during the opening of the ventricles or diastole.

If rigid vessels were compatible with the movements of animals, they would be preferable to elastic ones for carrying on the circulation, as in this case the heart would merely require to force on the blood without having to dilate the vessels. If, even with our imperfect knowledge of mechanics, we were asked to transmit fluid from one point to another, we would never dream of employing an elastic tube (a tube which can spontaneously open and close in parts is quite another matter). Still less would we think of distending the elastic tube with the power which should transmit the fluid, delegating the transmission at second hand to the recoil of an elastic apparatus. This, I repeat, with our imperfect knowledge of mechanics, we would not do. Can it be thought, then, that nature, perfect in all her operations, would employ a method to which we, with our limited knowledge and crude methods, would object? The vessels or ducts must of necessity be flexible: they form part of a living, moving mass, and must yield to accommodate themselves to the varying postures and shapes assumed by the organism to which they belong. It does not, however, follow from this that they are to be regarded as simply elastic tubes: on the contrary, we know that some of them pulsate—that is, spontaneously open and close in parts. We know further that all of them are supplied with nerves, and many of them with longitudinal and circular muscular fibres similar to those found in the intestines; the intestines exhibiting fundamental, well-marked, vermicular movements. Nor must it be forgotten that the presence of nerves and of muscular fibres is not necessary to the so-called contraction and relaxation of parts. The heart opens and closes while yet a mass of cells, without either cavities, blood, or muscular fibre; and the vacuoles or spaces in many plants open and close with a regular rhythm—the closure being rapid and the opening slow, as in the different parts of the heart. Here, of course, neither muscle nor nerves are present. It is therefore exceedingly improbable that the blood-vessels take no part in the circulation other than is produced by a mechanical recoil.

[1] Dr. Hoggan, in the *Edinburgh Medical Journal* (October 1872), states his belief that the heart dilates or expands in virtue of the blood forced into its parietes at each systole. This doctrine is, I believe, founded in error. The heart in the embryo pulsates while yet a solid mass of nucleated cells—that is, before it is supplied with blood-vessels and before cavities are formed in it. In the adult it pulsates after it is removed from the body, its cavities, which contain the blood, and which, according to Dr. Hoggan, indirectly force it into its ventricular walls, being laid open. The presence of blood is, moreover, not necessary to rhythmic movements, as plants and the lower orders of animals, which are devoid of blood, exhibit them. Dr. Hoggan's theory is not more satisfactory when applied to the lungs. If the lungs are expanded by the forcing of blood into their capillary vessels, then the lungs of the fœtus should be expanded, as their vessels are pervious, and the fœtal heart acts vigorously. Again, in the case of the adult lung, collapsed from fluid or air pressure exerted from without (the carnified lung of pathologists), the heart acts normally, but fails to arrest the mischief. If a lung be deprived of its residual air, it is impossible to inject the blood-vessels in its substance. In conclusion, if the blood in the vessels and capillaries of the lungs and heart caused their expansion, it is evident that this fluid, which is constant in amount in both, would prevent their contraction and destroy their rhythmic movements—that is to say, would render the alternate increase and diminution of the volume of the heart and lungs impossible. Dr. Liebermann, of Vienna, who wrote after Dr. Hoggan, but published before him, virtually endorses Dr. Hoggan's views.

[2] The small vessels are largely furnished with nerves, These diminish their calibre on the application of cold, and increase it on the application of heat.

If there is any truth in the theory that living structures accommodate themselves to the conditions in which they are placed, and that blood-vessels are opened rhythmically by the vital contractions of the ventricles, it is reasonable to conclude that the vessels of animals, being opened by the heart and allowed to close at brief intervals through innumerable lives (some of them very protracted), come ultimately to open and close of themselves, and to act either independently of or in conjunction with the heart. If the vessels were rigid and non-resilient, the blood would be forced along them by successive jerks, each jerk corresponding to the closing or systole of the ventricles. This is what actually happens when the heart is acting so feebly that it fails to distend the vessels, and evoke their elastic properties. Under these circumstances a very distinct venous pulse is felt, the elasticity which begets a continuous current being inoperative. The fact that a feeble heart can make its pulsations felt in the veins proves that considerably less power would suffice for carrying on the visible circulation if the vessels were rigid (they are virtually so in this non-distended condition). When the heart is acting normally, the column of blood in the vessels receives during the systole a smart tap, similar to that which a hammer produces when made to strike the end of a column of wood or other rigid material. This follows because fluids are very slightly compressible even under high pressures. The incompressibility of the fluid column of blood accounts for the extreme rapidity with which the pulsation communicated during the systole travels, the impulse at the heart and extremities being nearly

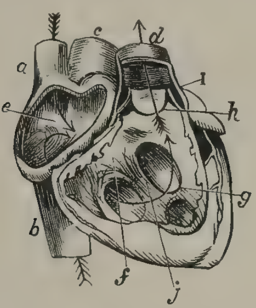


Fig. 164.

Fig. 165.

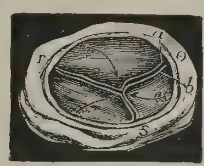


Fig. 166.

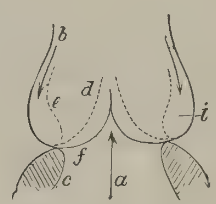


Fig. 167.

Fig. 164.—Pulmonic or right side of human heart. *e*, Right auricle; *g*, right ventricle; *a*, superior cava; *b*, inferior cava; *c*, aorta; *d*, pulmonic artery; *h*, segment of pulmonic semilunar valve; *i*, sinus of Valsalva; *f*, segment of tricuspid valve; *j*, musculus papillaris. The arrows indicate the direction in which the blood enters and leaves the right or pulmonic heart (after Gray).

Fig. 165.—Tricuspid valve in action seen from above (human). The segments are folded and twisted into each other by a screwing wedging motion (*vide* arrows *m*, *i*, *n*), occasioned by the spiral movements of the ventricles and the spiral impulse communicated to the blood contained within the right ventricle (the Author, 1864).

Fig. 166.—Semilunar valve of pulmonary artery in action, seen from above (human). Shows how, when the valve is closed, the segments *rs*, *so*, *or*, are folded upon themselves, and spirally wedged towards the axis of the vessel (*vide* arrows). To produce a perfect closure the margins (*a*, *b*) of the segments must flatten against each other, the extent of the flattening increasing as the pressure exerted by the blood is augmented (the Author, 1864).

Fig. 167.—Diagram showing sectional view of the sinuses of Valsalva (*i*) in the human pulmonary artery. Shows also the different positions assumed by the segments of the pulmonic semilunar valve when at rest and in action. *a*, Arrow indicating the course taken by the blood on leaving the right ventricle. The blood in its passage pushes aside the segments (*f*) of the valve, until they assume the positions *d* and *e*; *d* represents the position of the segments when at rest and floating in blood; *e*, their position when pushed aside by the advancing tide; and *f* their position when closed. The arrow *b* indicates the direction taken by the blood when it retrocedes and closes the valves; *c*, base of right ventricle (infundibuliform portion) (the Author, 1864).

synchronous. This rapidity of travel is accounted for by the blood ejected from the ventricles displacing that immediately in front of it, this in turn displacing the blood in front of it, and so on *ad infinitum*, until the capillaries are reached by the advancing column on the one hand, and the heart by the receding column on the other. The transmission of the different portions of blood meted out by the ventricles, at each systole, produces the pulse at the wrist and other parts of the body. The all but incompressible nature of the fluid column of blood in the vessels, taken in connection with the fact that the blood is moved on in relays, enables the heart, as has been stated, to exert a sucking as well as a propelling power.

§ 137. The Valves of the Right Heart of the Mammal.

To facilitate the circulation of the blood through the heart, the valves, sluices, or gateways of the heart are constructed to open in only one direction; thus, the tricuspid valve opens towards the right ventricle (Fig. 164, *f*), and the semilunar one (Fig. 164, *h*) towards the pulmonary artery; the blood is consequently compelled to travel from the right auricle (Fig. 164, *a*) to the right ventricle (*g*), and from the right ventricle to the pulmonary artery (*d*) and lungs. It is only when the valves are diseased and incompetent that even a slight amount of regurgitation is possible, either in the tricuspid (Fig. 165) or semilunar valve (Fig. 166).

When the blood is being forced from the right ventricle, it is projected as a fluid wedge (the infundibulum is

wedge-shaped). The fluid wedge throws the segments of the semilunar valves back into the sinuses of Valsalva, as opening folding-doors are forced into recesses formed for their reception (Fig. 167, *i*). This has the effect of increasing the orifice of the pulmonary artery very considerably. But the recesses or sinuses of Valsalva (Fig. 167, *i*) have yet another function. They are large enough always to contain a certain amount of residual blood, which by its mere weight tends to force the segments spirally towards the axis of the pulmonary artery, the instant the systole of the right ventricle ceases. This movement is favoured by the sucking power exerted by the right ventricle when it expands (*vide* arrow *b* of Fig. 167). The segments of the semilunar valve, in addition, incline towards the axis of the vessel when immersed in fluid and left to themselves (Fig. 167, *d*). In virtue of this mechanical adaptation, the margins of the segments are forced towards each other by the slightest reflux; the reflux, when it increases, producing a folding or wedging of the segments into each other as shown at Fig. 166. The tricuspid valve acts on the same principle (Fig. 165), but has a more complicated function to perform, from its guarding the right auriculo-ventricular orifice, the size of which varies as the heart opens and closes, and from the fact that it is connected by a series of tendinous bands, the chordæ tendineæ,[1] to actively-contracting structures, namely the musculi papillares (*f*, *j*, of Fig. 164).

The action of the tricuspid valve is therefore vito-mechanical, while that of the semilunar is nearly, if not wholly, mechanical. The parts which correspond to the sinuses of Valsalva in the right ventricle are the spaces to the outside of each of the segments of the tricuspid.

The blood is forced by the right ventricle into the lungs with considerable energy. Much of the force exerted is, however, dissipated by the rapid bifurcation of the pulmonary arteries, these dividing and subdividing at such short distances as effectually to slow the current before it reaches the delicate capillary blood-vessels of the lungs. This is a wise provision, for in cases of hypertrophy of the right ventricle, it happens not unfrequently that some of the smaller vessels of the lungs are ruptured, and pulmonary apoplexy induced.[2]

§ 138. Safety-valve Action of the Tricuspid.

It has been thought by some,[3] that, in order to prevent injury to the pulmonary organs, the tricuspid valve is never exactly competent, and that, when the rigid ventricle closes, the blood, which cannot be forced into the lungs without producing mischief, escapes into the right auricle, and thence into the cavæ. I am not disposed to look favourably on this argument, as it assumes an imperfection in the circulatory apparatus, which I do not find to exist. In the fish, where there is no reason to suspect a regurgitant action, the gills are situated in close proximity to the heart, but no harm accrues from the proximity, although the ventricle and bulbus arteriosus are both exceedingly powerful structures.[4] The walls of the right and left ventricles of the mammal, as has been already stated, are of the same thickness in the fœtus until quite near the full term. Towards the end of the full term and after birth, when the pulmonic circulation is established, the right ventricular walls apparently cease to grow, while the left ventricular walls become thicker and stronger. Here is an accommodating process which produces the exact amount of pressure required for forcing the blood without danger through the lungs and through the system. If the blood which should be forced into the lungs was allowed to regurgitate into the right auricle, and thence into the cavæ, it would tend to disturb the whole circulation, for any impediment at one part would necessarily react upon every other part. We have, moreover, direct proof that the tricuspid valve is competent. If, for example, I push a rigid tube past the semilunar valve of the pulmonary artery and fix it firmly in that vessel, and then sink the right heart in water, I find that, by blowing into the tube, the segments of the tricuspid are spirally floated up by the water, approximated, and apposed so perfectly that not a single drop of fluid is permitted to regurgitate (Fig. 165).

I have repeatedly performed this experiment, and always successfully. If regurgitation is a serious matter in the bicuspid and semilunar valves, it would be illogical to infer that it was harmless in the tricuspid. The express function of the tricuspid and all other valves is to prevent regurgitation. Not only is the power of the right ventricle exactly suited to the requirements of the pulmonic circulation, but the pulmonic vessels are provided with that degree of elasticity and of vital movement which enables them to reciprocate with the utmost nicety. In virtue of this arrangement the blood arrives at the capillaries of the lungs, and the vessels of the entire system, at the speed and in the quantity best suited for each. The slowing of the current of the blood is necessary for the purposes of respiration, nutrition, growth, waste, &c. The slowing of the blood in the delicate capillaries of the lungs increases

[1] In the substance of the pulmonic semilunar valve, similar bands are found; and in certain cases of disease they are dissected out, and greatly resemble the chordæ tendineæ of the tricuspid. Both valves are evidently formed on the same type.

[2] Pulmonary apoplexy is usually associated with disease and constriction of the mitral valve, the constriction obstructing the flow of blood into the left ventricle, and damming it up in the lungs.

[3] Mr. T. W. King, in Guy's Hospital Reports for April 1837, No. IV.

[4] For explanation of the manner in which the ventricle and bulbus arteriosus of the fish act, see under "Circulation in the Fish," p. 473.

the opportunities afforded this fluid for taking in oxygen and giving off carbonic acid and other matters. These interchanges effected, the blood is urged on, partly by the closure of the right ventricle, partly by the opening of the left auricle, and partly by atmospheric pressure, into the pulmonary veins, which debouch by four openings into the left auricle.

§ 139. The Left Heart and Valves of the Mammal.

As there are no tissues of importance to be nourished by the blood in the pulmonary veins, it follows that these can exert no influence in drawing the blood into the left auricle. This function is performed by the closing of the right ventricle, by the vital expansion of the left auricle, aided by atmospheric pressure and by the respiratory movements. Once in the left auricle, the arterial blood is projected thence by the closing of the left auricle through the left auriculo-ventricular opening into the left ventricle, which simultaneously expands to receive it. It is then forced by the closing of the left ventricle through the aorta, and by means of its branches through the whole system. The course of the current through the left heart is determined, as in the right, by the presence of two sets of valves, namely, the bicuspid or mitral and the aortic semilunar valve. These valves resemble the tricuspid and pulmonic semilunar valves just described, so that further allusion to them at this stage is unnecessary.

§ 140. Circulation in the Head, Liver, and Erectile Tissues.

In mammals the circulation in the head, liver, and erectile tissues is worthy of a separate description. The supply of blood to the brain is comparatively very large, and is furnished by the two internal carotid and the two vertebral arteries.[1] These spread out on the base of the brain to form the circle of Willis, which may be regarded as a reservoir for providing a regular supply of blood to the arteries of the organ. The arteries break up into an infinite number of minute branches in the pia mater, from whence they betake themselves to the brain-substance. The blood is returned by numerous small veins to the venous sinuses, which are remarkable for their great size, and the fact that they are formed on the one aspect by the tough dura mater, and on the other by the inner table of the cranium, so that their walls may, in a great measure, be regarded as incompressible. This led to the belief that the quantity of blood in the brain is always the same. Dr. Kellie endeavoured to establish this view by experiment. He found that if an animal was bled to death the quantity of blood in the brain remained the same, while the system generally was drained; but that if the cranium was perforated, and air admitted to the brain before the bleeding took place, the brain and system generally were blanched equally.

Dr. Burrows obtained opposite results, so that the question is still *sub judice*. The erectile organs are rendered tense by a determination of blood to the very extensive and complicated venous plexuses contained in their interior. Professor Kölliker is of opinion that the plexuses during the non-erectile state are compressed by the habitual contraction of organic muscular fibres, and that in the erectile state the action of these fibres is suspended by nervous influence, the blood being permitted to distend the plexuses mechanically. It is more natural to suppose that the organic muscular fibres alluded to by Kölliker are not in a state of habitual contraction, that is, constant activity, in the non-erectile state, but resting; the muscles only being active and expanding during the erectile state. It is difficult to understand how a muscle should be called upon to perform work constantly, when the same result might be obtained by occasional effort exerted at long intervals. Instead of regarding the muscle as habitually contracted, we have only to imagine that it occasionally dilates. These remarks also apply to the muscles known as sphincters. It seems irrational to invest a muscle with the power of contracting or closing, and to divest it of the power of elongating and expanding.

The venous blood of the principal abdominal viscera passes through the liver on its way to the heart. The following is the arrangement: The blood supplied by the cœliac and mesenteric arteries to the abdominal viscera is not returned directly to the heart by their corresponding veins, as occurs in other parts of the body. The veins of the stomach and intestinal canal, of the spleen, pancreas, mesentery, omenta, and gall-bladder, unite together below the liver into one large vessel, the trunk of the vena porta, which branches out again and distributes to the liver by its ramifications the whole of the venous blood coming from the above-mentioned organs. The blood of the vena porta, being joined in the minute branches by that of the hepatic artery, passes into the smallest ramifications of the hepatic veins, by the principal trunks of which the venous and arterial blood circulated through the liver is carried to the inferior vena cava, and thus reaches at last the right side of the heart.

[1] Dr., now Sir J. Crichton Browne, in an able article "On Cranial Injuries and Mental Diseases," referring to a case where a portion of bone two inches by one had been removed from the upper part of the right frontal region on account of injury, states that the cicatrix pulsated visibly, and that the vascular changes were so rapid and considerable, as to impress him with the idea that the brain in some respects resembles erectile tissue. (West Riding Lunatic Asylum Medical Reports, vol. ii. pp. 101, 102; 1872.)

The great arteries are important accessories of the circulation in the mammal, inasmuch as they transmit the blood to and from the heart, which is the central engine for its propulsion. They are, however, as has been stated, only accessories. The most important functions performed by the vessels are delegated to the capillaries, a mazy labyrinth of minute vessels which ramify and inosculate in every conceivable direction. It is within those delicate capillary tubes that the blood meanders and literally irrigates the tissues, each tissue selecting and drawing through the capillary walls whatever it requires; or, what comes very much to the same thing, having forced upon it by an osmotic action those peculiar fluids for which it has an affinity, and which are best adapted for its support and nourishment. The small arteries and capillaries are deserving of very particular attention, the more especially as their structure and movements indicate the structure and movements of the larger vessels; these, again, indicating the structure and movements of the heart, which in its turn, curiously enough, foreshadows the structure and movements of all the other muscles, voluntary and involuntary.

§ 141. The Lymphatic and Capillary Vessels of Animals.

The capillaries furnish the simplest form of vessel. They may be divided into two kinds, namely, such as convey red blood, and such as convey a pale watery or milky fluid, the lymph or chyle. The lymphatics are intimately connected with the process of digestion in the alimentary canal and tissues generally. "The *lymph*," Mr. Huxley observes, "like the blood, is an alkaline fluid, consisting of a plasma and corpuscles, and coagulates by the separation of fibrine from the plasma. The lymph differs from the blood in its corpuscles being all of the colourless kind, and in the very small proportion of its solid constituents, which amount to only about five per cent. of its weight. Lymph may, in fact, be regarded as blood *minus* its red corpuscles and diluted with water, so as to be somewhat less dense than the serum of blood, which contains about eight per cent. of solid matters. A quantity of fluid equal to that of the blood is probably poured into the blood daily from the lymphatic system. This fluid is in great measure the mere overflow of the blood itself—plasma which has been exuded from the capillary blood-vessels into the tissues, and which has not been taken up again into the venous current; the rest is due to the absorption of chyle from the alimentary canal." In reptiles and birds the lymphatics are provided with pulsating sacs or hearts and valves—an arrangement which insures that the lymph shall travel in only one direction, namely, towards the general circulation. The lymph in man is discharged into the general current of the circulation by two apertures situated between the angles of junction of the right and left internal jugular and right and left subclavian veins. The openings by which the lymph is discharged into the general circulation are each provided with a pair of valves to prevent regurgitation of the venous blood. The lymphatic vessels are to be regarded as the feeders of the vascular vessels, in the same sense that the vessels of the roots of a tree are to be considered the feeders of the vascular vessels in the trunk of the tree. In this respect the sanguineous circulation is to be looked upon as a development of the chyliferous. The colourless corpuscles, which are so abundant in the lymphatic vessels, reappear in the capillaries of the vascular system, and are known as the white corpuscles of the blood. They are possessed of independent movements and change shape. They have attracted an unusual share of attention of late from the power they possess of forcing themselves through the thin walls of the capillaries. The capillaries vary in size from $\frac{1}{1500}$ to $\frac{1}{2000}$ of an inch in diameter, and form an infinite variety of minute loops, being now straight, now slightly waved, and now tortuous. They generally form a network so dense that the point of a pin cannot be introduced without lacerating some of them. The capillaries of the vascular system are placed midway between the arteries and veins—the arteries conducting to and the veins from them. Around and between the capillaries is a system of still more minute vessels, the hyper-vascular canals.

The capillaries form a sort of neutral territory, in which the blood moves more slowly in order to afford the tissues the fullest opportunity of imbibing nourishment and discharging effete matter. They form a through route for the blood, but one with numerous convenient stages for the interchange of the good and bad things of the economy. The circulation in these minute vessels may not inaptly be compared to a river which carries a blessing wherever it goes, giving freshness and beauty to the country, and purifying the city by removing its sewage. The capillaries of the lymphatic system, so far as known at present, do not form a through route, but begin in the tissues by blind ends, resembling the tips of the roots of plants. The lymphatic system would therefore appear to be the precursor of the vascular system, and to form a connecting link between the vegetable and animal. The lymphatics are eminently adapted alike for conveying new and old ingredients into the blood. Like the roots of plants, they are endowed with selective powers, certain of their terminals taking up new matter, others matter which has been partially used, and others effete or waste matter.

§ 142. Structure of the Capillaries and Small Arteries and Veins; Vessels Close and Elongate, and Open and Shorten.

The walls of the capillaries are composed of a thin, structureless membrane, in which small oval bodies, termed nuclei, are embedded. They bear a considerable resemblance to the walls of the cells and young vascular bundles of plants.

The capillaries differ from the small arteries and veins in being of a uniform calibre, and in having very delicate, thin, permeable walls. The thin permeable walls permit the fluid contents of the capillaries to escape into the surrounding tissues, which are in this manner irrigated and nourished very much in the same manner that the growing parts of a plant are nourished by the imbibition of saps. In either case, the growing parts, that is, the ultimate particles of the plant and animal, are outside the vessels.[1] In this sense the fœtus is also outside the circulation in the mother. The capillaries further differ from the small arteries and veins in this, that the latter possess a more complex structure and thicker walls. Thus, proceeding from without inwards, the walls of the smaller vessels consist, first, of a sheath of fibrous tissue, the fibres of which pursue a more or less longitudinal direction;[2] second, of a muscular layer composed of flattened, spindle-shaped bands, with elongated nuclei, these bands running transversely or across the vessel;[3] and, third, of a layer of very delicate, elongated, epithelial cells, the oval nuclei of which are arranged longitudinally or at right angles to those of the muscular fibres.[4]

This arrangement accounts for the reticulated appearance presented by the smaller vessels (Plate lxxxiv., Fig. 2, A, B, p. 322), and for the fact first promulgated by John Hunter, that the vessels are extensile and retractile in their length and breadth. As the walls of the vessels become thicker, they lose the permeability which is a distinguishing feature of the capillaries. The vessels, however, have what may be regarded as an equivalent added, namely, muscular fibres and nervous twigs, which regulate their calibre and consequently the exact amount of blood supplied to the capillaries and to the tissues.

When the muscular layer of a small vessel closes in a direction from without inwards, the vessel is lengthened and narrowed (Plate lxxxiv., Fig. 3), from the fact that all muscles, when they shorten in one direction, lengthen in another and opposite direction (Plate lxxxiii., Fig. 2, D); muscular movements being due not to any increase or diminution in the bulk of the muscles, but to a change of shape in their sarcous elements (Plate lxxxiii., Fig. 1). The fibres of the central or transverse muscular layer of a small vessel are arranged, as explained, at right angles to the fibres composing the external fibrous layer, and the delicate elongated epithelial cells constituting the internal layer. When, therefore, the fibres of the central or transverse muscular layer close or shorten, they elongate and stretch the elements composing the external and internal layers; these, in virtue of their elasticity, the instant the closure ceases, assisting the central layer in regaining its normal dimensions. We have thus two forces at work—the muscular force and the elastic force. As, however, these forces act at right angles to each other, and the structures in which they reside are connected, it follows that when the one acts the other must act also. It is thus that muscular and elastic force can act in unison, and by their united efforts produce a common result.

§ 143. Elastic and Vital Properties of Vessels.

The influence exerted by the elasticity of vessels in producing a steady continuous flow of blood is well marked. There is, however, reason to believe that the elastic properties of vessels have been overrated. It must never be overlooked that the movements in vessels have their origin in muscles, either the muscles of the heart, or the muscles of the vessels themselves. Nor must it be forgotten that the muscular layer of even the smallest vessel can by itself increase or diminish the calibre of the vessel, the muscular fibres determining the amount and direction of the movement. This is proved by the fact that a small artery can be made to diminish its circumference by the application of cold, and to increase it by the application of heat. That the closing or partial closing and elongating of a small vessel is directly due to the shortening of the muscular fibres comprising the central layer of the vessel, is evident from the direction of the muscular fibres (they are obliquely circular, and invest the vessel more or less transversely). That the opening or partial opening of a small vessel is only partly due to the recoil of the fibrous

[1] There are portions of the body, such as the nails, hair, teeth, cartilage, epithelium, epidermis, &c., which are not supplied with vessels at all. These structures are still further removed from the general circulation, but they are not beyond the reach of its influence.

[2] The external or areolar fibrous coat consists of areolar tissue and longitudinal elastic fibres; it also contains, in some of the larger veins, a longitudinal network of non-striated muscular fibres, as in the whole length of the inferior vena cava, the renal, azygos, and external iliac veins, and in all the large trunks of the portal venous system, and in the trunks of the hepatic veins. ("Gray's Anatomy," p. 401.)

[3] The middle layer in the *larger* vessels, according to Gray, consists of numerous alternating layers of muscular and elastic fibres, the fibres of the former running across the vessel, those of the latter in the direction of its length. This layer is thicker in the arteries than in the veins.

[4] The internal layer in the *larger* vessels consists, in Gray's opinion, of an epithelial lining, supported on several laminæ of longitudinal elastic fibres. This layer is less brittle in veins than in arteries.

and elastic elements, is apparent from this, that they invest the vessel in the direction of its length. At most, therefore, the elastic elements, when they recoil, shorten the vessel. It remains for the muscular element to elongate transversely, and by its elongation to expand and widen the vessel. The power to increase and diminish the size of the vessel resides chiefly if not exclusively in the muscular fibres, these, as already explained, having a centrifugal and centripetal action. The elastic structures are more developed in the vessels than in the heart and other hollow viscera, the latter organs being comparatively inelastic. The voluntary muscles, again, are less elastic than the involuntary ones. In proportion as the muscular movements become exact the elastic structures disappear. In order to have a perfect co-ordination in muscular movements, all the muscles involved, whether these be extensors or flexors, pronators or supinators, abductors or adductors, must take part (Plate lxxxiii., Fig. 4, p. 320). Nothing is left to chance, and as a consequence elasticity is reduced to a minimum. If a vessel was composed solely of muscular fibres it would not be so strong, neither would its movements be so rapid or continuous, as one composed partly of muscular and partly of elastic fibres. A muscle is capable of acting in two directions ; it can first elongate and then shorten itself ; but these are opposite movements, and between them a pause or halt (the dead point of engineers) inevitably occurs. Elasticity gets the muscle over this dead point, and decreases the duration of the pause. The value of elasticity in interrupted or rhythmic movements, such as those employed in the circulation, becomes therefore very obvious. There are many examples to prove that elasticity plays a part not only in involuntary movements, but likewise in voluntary ones. The wing of a bird, for instance, is flexed almost exclusively by the action of powerful elastic ligaments, extending between the shoulder and wrist, and between the elbow and hand. These ligaments gradually close or flex the wing towards the termination of the down-stroke,[1] and are put upon the stretch towards the termination of the up-stroke, by the shortening of the powerful pectoral and other muscles. Nearly half of the wing movements are therefore performed by a purely mechanical arrangement.[2] Numerous other examples might be cited, but this is a very obvious one. It suffices, when elastic structures are present, if the muscles stretch them when they shorten ; the elastic structures, when they shorten, assisting in the elongation of the muscular ones. The elastic and muscular structures mutually operate on each other. What would be a purely vital act is by this arrangement rendered vito-mechanical, and no better illustration can be given of the fact that animate, and what may be regarded as inanimate, matter can be made to reciprocate and work in harmony. The difference (but it is an all-important one) between a living vessel and an elastic tube amounts to this : The walls of a living vessel can oscillate or vibrate on either side of a given line, this line corresponding to their position of rest.[3] An elastic tube, on the other hand, can only be made to vibrate on one side of a given line. In other words, it can be made to open by being artificially distended, but it cannot be made to close. Thus if the circle *a* of Plate lxxxiv., Fig. 5, p. 322, be made to represent an elastic tube, it may be stretched until it assumes the dimensions *b*, but it cannot be made to assume the dimensions *c*. This the living vessel can readily do from the power it possesses of oscillating on either side of the circle *a*.

All attempts, therefore, at reproducing by merely elastic tubes and cavities the structure and forces employed in the circulation are more or less fallacious. Another marked difference between a hollow muscle and an elastic tube is to be noted. An elastic tube, when allowed to return to its position of rest after being put upon the stretch, is active throughout its entire substance at one and the same time. A living muscle, on the contrary, moves in parts—its action being a progressive wave action. Bowman is very explicit on this point. He states, first, that active contraction never occurs in the whole mass of a muscle at once, nor in the whole of any one elementary fibre, but is always partial at any one instant of time ; second, that no active contraction of a muscle, however apparently prolonged, is more than instantaneous in any one of its parts or particles ; and therefore, third, that the sustained active contraction of a muscle is an act compounded of an infinite number of partial and momentary contractions, incessantly changing their place and engaging new parts in succession ; for every portion of the tissue must take its due share in the act. From this it follows that a muscle rests in its sarcous elements or ultimate particles even when it is working. These points are illustrated at Plate lxxxiii., Fig. 2, C, D, p. 320.

§ 144. Structure of the Large Arteries and Veins.

As the vessels increase in size and their walls become thicker and more complex, the structures composing them are arranged at right angles and obliquely, but always in pairs and symmetrically. Regarding the composition of the veins, there is considerable difference of opinion, authorities not being agreed as to either the number or nature of the

[1] They are prevented from closing the wing suddenly, after the manner of springs, by the resistance offered by the air to the expanded wing as it descends.

[2] "On the Mechanical Appliances by which Flight is attained in the Animal Kingdom," by the Author (*Trans. Lin. Soc. of London*, vol. xxvi.). "On the Physiology of Wings," by the Author (*Trans. Roy. Soc. of Edinburgh*, vol. xxvi.).

[3] Precisely similar remarks may be made of the parietes of the different compartments of the heart.

coats. This may in part be explained by the variation in the thickness of the coats themselves, these, according to John Hunter,[1] becoming thinner and thinner in proportion to the size of the vein, the nearer the vein approaches the heart. In moderate-sized veins an external, a middle, and an internal coat are usually described; the first consisting of cellular, fibrous, and elastic tissue, interlacing in all directions; the second, of waved filaments of areolar tissue, with a certain admixture of non-striped muscular fibres, which run circularly, obliquely, or even longitudinally;[2] the third, consisting of one or more strata of very fine elastic tissue, minutely reticulated in a longitudinal direction, the innermost stratum (when several are present) being lined by epithelium. Of these layers the second and third, from the fact of their contributing to the formation of the venous valves, are the most important. The coats of the veins, as has been long known, are tough, elastic, and possessed of considerable vital contractility, that is, they have the power of opening and closing within certain limits. Of these qualities, the toughness prevents undue dilatation of the vessel when distended with blood; the elasticity and the power the vessel possesses of opening and closing assisting the onward flow of that fluid, and *tending to approximate the segments of the valves.* As the valves of the veins are very ample and very flexible, they readily accommodate themselves to the varying conditions in which they are placed by the elasticity and vital properties of the vessel, and by the reflux of the blood.

The coats of the arteries, as is well known, are comparatively much thicker than those of the veins, while the layers composing them are more numerous. The external coat, according to Henle, consists of an outer layer of areolar tissue in which the fibres run obliquely or diagonally round the vessel, and an internal stratum of elastic tissue; the middle coat in the largest arteries, according to Raüschel, being divisible into upwards of forty layers. The layers of the middle coat consist of pale, soft, flattened fibres, with an admixture of elastic tissue; the fibres and elastic tissue being disposed more or less circularly round the vessel. The internal coat is composed of one or more layers of fibres, so delicate that they constitute a transparent film, the film being perforated at intervals, and lined with epithelium. From this account it will be obvious that the large veins and arteries possess a much more complex structure than the smaller vessels—these, again, being more highly differentiated than the capillaries. The large arteries and veins, in fact, present a structure remarkably resembling that found in the ventricles of the mammalian heart; thus they have fibres running longitudinally, obliquely, very obliquely, and transversely; the fibres intersecting at a great variety of angles, and being arranged with a view to co-ordinating each other. The arteries, as might be expected from their structure, and as was proved by the admirable experiments of John Hunter, whose beautiful preparations I have had an opportunity of studying, possess, in addition to the vital powers peculiar to them, a considerable degree of elasticity, and are extensible and retractile both in their length and breadth; the power of recovery, according to that author, being greater in proportion as the vessel is nearer the heart. From this it follows that the pulmonary artery and aorta are most liable to change in dimensions. As, however, any material alteration in the size of the pulmonary artery and aorta at their origins would interfere with the proper function of the semilunar valves situated at their orifices, it is curious to note that the great vessels arise from strong and comparatively unyielding fibrous rings. These rings (particularly the aortic one) are so dense as to be almost cartilaginous in consistence, and Professor Donders[3] has discovered that they contain stellate corpuscles similar in many respects to those stellate and spicate corpuscles found in many forms of cartilaginous tumours. They have been more or less minutely described by Valsalva,[4] Gerdy,[5] Dr. John Reid,[6] and the late Sir W. S. Savory,[7] and merit attention because of their important relations to the segments of the semilunar valves. The following description of them has been drawn up by me from my private notes of a large number of dissections of the human heart, several of which are deposited in the Museum of the Royal College of Surgeons of England, London. Each ring consists, as was shown by Reid, of three concave portions. Each concave portion is directed from above downwards, and from without inwards, and as it unites above with that next to it, the two when taken together form a conical-shaped prominence which is adapted to one of the three triangular-shaped interspaces occurring between the three segments of the semilunar valves. The ring surrounding the pulmonary artery is broader, but not quite so thick as that surrounding the aorta, and both are admirably adapted for the reception of the large vessels which originate in three festooned borders. This point is illustrated at G and H of Fig. 5, Plate lxxxv., p. 325.

[1] "Hunter on the Blood," pp. 180, 181.
[2] Dr. Chever says, that in the deep, as well as in some of the superficial, veins of the trunk and neck, the middle coat is composed of several layers of circular fibres, with only here and there a few which take a longitudinal course; while the middle coat of the superficial and deep veins of the limbs consists of a circular layer, and immediately within this of a strong layer of longitudinal fibres. (*Med. Gazette*, 1845, p. 638.)
[3] "Onderzockingen betrekkeligh den bouw van het menchelijke hart," in *Nederlandsch Lancet* for March and April 1852.
[4] "Opera Valsalvæ," tom. i. p. 129.
[5] *Journal Complimentaire*, tom. x.
[6] "Cyc. Anat. and Phys.," article "Heart," pp. 588, 589. London, 1839.
[7] Paper read before the Royal Society in December 1851.

STRUCTURE OF THE HEART OF THE MAMMAL

§ 145. The Arrangement of the Muscular Fibres in the Auricles and Ventricles.

The auricles of the mammalian heart, as already explained, are two in number, a right and a left. They are irregularly-shaped muscular cavities or receptacles which collect venous and arterial blood; the right communicating with the ascending and descending cavæ, the left with the pulmonary veins. The cavæ and pulmonary veins are invested with muscular fibres of considerable strength, which confer on these vessels a certain amount of vermicular movement. The muscular fibres of the auricles are arranged at right angles and obliquely to each other, as in the ventricle of the fish and reptile (Figs. 168 and 170). The fibres in the auricular appendages are disposed in ridges to form the musculi pectinati. Where most plentiful, they are arranged in layers. They are circular in some cases, looped in others, and occasionally plicate. They are specially arranged to procure strength, and with a view to opening and closing the auricular cavities, which they do by alternate centrifugal and centripetal movements. The auricles when closed contain a certain amount of residual blood, and in this respect they differ from the ventricles, which have the power of completely expelling it (Figs. 2–7 of Plate lxxxv., p. 325). The auricles serve as reservoirs, and are to be regarded as intermediate structures between the large veins and ventricles. The auricles are anatomically distinct from the ventricles, and in hearts which are boiled the auricles and ventricles may be separated from each other without rupturing a single fibre. The auricles are structurally continuous with the large veins (the cavæ and pulmonary veins), from which they are not separated by valves as the auricles are from the ventricles. From this it follows that when the auricles close, the pressure exerted by them is away from, as well as towards, the ventricles; an indirect proof that the auricles by their closure do not forcibly dilate the ventricles. It ought, however, to be stated that the veins are more or less closed at the commencement of the auricular contraction. The great veins and auricles exhibit spontaneous and rhythmical movements, the veins closing when the auricles open, and *vice versâ*. Analogy favours the belief that the great vessels conducting from the heart (pulmonary artery and aorta), as well as those conducting to it (venæ cavæ and pulmonary veins), participate in those rhythmical movements. The bulbus arteriosus of fishes and reptiles (the homologues of the first part of the aorta in mammals), as I have already shown, opens and closes like the different parts of the heart itself. The muscular fibres composing the auricles are more plentiful in some regions than in others. In some places they are so sparse as to render the walls of the auricles transparent, while in others they are grouped and superimposed, the walls under these circumstances being quite an eighth of an inch in thickness (Figs. 168 and 170).

FIG. 168. FIG. 169. FIG. 170.

FIG. 168.—Anterior aspect of the auricles, showing the distribution of the muscular fibres (human). *a*, Pulmonary veins; *b*, vena cava superior. The great vessels (*a* and *b*) are invested with muscular fibres, and have distinct movements (after Gerdy).

FIG. 169.—Ideal transverse section of the ventricles, showing how the septum which divides the right and left ventricles from each other is formed. The heart originally consists of a single tube. At an early period it is divided by a longitudinal and transverse fold into four compartments, two auricles and two ventricles. The ventricles (*b* and *c*) are separated from each other by the fold (*a*) passing in an antero-posterior direction until it touches the posterior wall (*d*) of the ventricles, into which it penetrates and becomes fixed. The two halves of the fold likewise interpenetrate, the septum becoming of nearly the same thickness as the left ventricle, which is the typical ventricle. This accounts for the fact that the muscular fibres are continuous on the posterior aspect of the ventricles and interrupted on the anterior aspect, and hence the old idea that the ventricles are two muscles enveloped in a third. These points are explained at length in my memoir "On the Arrangement of the Muscular Fibres in the Ventricles of the Vertebrata"; *Phil. Trans.* 1864 (the Author).

FIG. 170.—Posterior aspect of the auricles, showing the distribution of the muscular fibres (human). *a*, *a*, Pulmonary veins; *c*, vena cava inferior. These are surrounded by muscular fibres, and take part in forcing the blood into the auricles (after Gerdy).

The ventricles of the mammalian heart, like the auricles, are two in number, a right and a left. They form a wedge-shaped, hollow, muscular mass, which is slightly twisted upon itself, particularly at the apex. The base of the wedge is directed upwards, and to this portion the auricles are attached, the auricles fitting into the right and left auriculo-ventricular openings, as stoppers into the necks of bottles. The auricles adhere to the fibrous rings investing the auriculo-ventricular orifices (Fig. 5, *c*, *d*, of Plate lxxxv., p. 325), but none of the muscular fibres of the auricles are continuous with those of the ventricles. The arrangement of the muscular fibres in the ventricles is exceedingly intricate, and requires careful description. Considered as a muscle, the heart, especially the ventricular portion of it, is peculiar. Being in the strictest acceptation of the term an involuntary muscle, its fibres nevertheless possess the dark colour and transverse markings which are characteristic of the voluntary muscles (Plate lxxxv.,

Fig. 1, H, p. 325). Unlike the generality of voluntary muscles, however, the fibres of the ventricles, as a rule, have neither origin nor insertion, that is, they are continuous alike at the apex of the ventricles and at the base. They are further distinguished by the almost total absence of cellular tissue as a connecting medium ; the fibres being held together partly by splitting up and running into each other, and partly by the minute ramifications of the cardiac vessels and nerves. The little cellular tissue there is, is found more particularly at the base and apex of the ventricles, and is so trifling in quantity as to be altogether, though wrongly, denied by some. Occasionally a small rudimentary bone shaped like a ploughshare occurs at the base of the ventricles in the ox and some of the larger animals. It has, however, no significance, as no muscular fibres are attached to it.

When the vessels of the ventricles are injected in the cold state with some material which will stand heat (as, for example, a mixture of starch and water), and the heart parboiled, the larger trunks from either coronary artery are seen to give off a series of minute branches which penetrate the ventricular walls in a direction from without inwards. These branches, when the dissection is conducted to a certain depth, resemble so many bristles transfixing the ventricular walls. As, moreover, the cardiac nerve-trunks accompany the trunks of the coronary vessels, while the nerve-filaments cross the smaller branches of the vessels and muscular fibres (to both of which they afford a plentiful supply of nerve-twigs), the influence exerted by the vessels and nerves in uniting or binding the muscular fibres to each other is very considerable.[1]

Of the various modes recommended for preparing the ventricles prior to dissection, I prefer that of continued boiling. The time required for the human heart and those of the small quadrupeds, as the sheep, hog, calf, and deer, may vary from four to six hours ; while for the hearts of the larger quadrupeds, as the horse, ox, ass, &c., the boiling should be continued from eight to ten hours ; more than this is unnecessary. A good plan is to stuff the ventricular cavities loosely with bread-crumbs, bran, or some pliant material before boiling, in order to distend without overstretching the muscular fibres. If this method be adopted, and the ventricles soaked for a fortnight or so in alcohol before being dissected, the fibres will be found to separate with great facility. Vaust recommended that the heart should be boiled in a solution of nitre ; but nothing is gained by this procedure.

The manner in which the muscular fibres are attached to each other, while it necessarily secures to the ventricles considerable latitude of motion, also furnishes the means whereby the fibres composing them may be successfully unravelled ; for it is found that by the action of certain reagents, and the application of various kinds of heats, as in roasting and boiling, the fibres may be prepared so as readily to separate from each other in layers of greater or lesser thickness. The chief peculiarity consists in the arrangement of the fibres themselves—an arrangement so unusual and perplexing that it has long been considered as forming a kind of Gordian knot in anatomy. Of the complexity of the arrangement I need not speak ; suffice it to say that Vesalius, Albinus, Haller,[2] and De Blainville [3] all confessed their inability to unravel it.

Having, in the summer of 1858, made numerous dissections of the ventricles, upwards of a hundred of which are preserved in the Anatomical Museum of the University of Edinburgh,[4] I arrived at results which appear to throw additional light on this complex question, and which seem to point to a law in the arrangement, simple in itself, and apparently comprehensive as to detail.[5]

The following are a few of the more salient points demonstrated in connection with this investigation :—

I. By exercising due care, I ascertained that the fibres constituting the ventricle are coiled upon each other in such a manner as readily admits of their being separated by dissection into layers or strata, the fibres of each layer being characterised by having a different direction.

II. These layers, owing to the difference in the direction of their fibres, are well marked, and seven in number, namely, three external, a fourth or central, and three internal.

III. There is a gradational sequence in the direction of the fibres constituting the layers, whereby they are made gradually to change their course from a nearly vertical direction to a horizontal or transverse one, and from the transverse direction back again to a nearly vertical one. Thus, in dissecting the ventricles from without inwards, the fibres of the first layer, which run in a spiral direction from left to right downwards, are more vertical than those of the second layer, the second than those of the third, the third than those of the fourth—the fibres of the fourth layer having a transverse direction, and running at nearly right angles to those of the first layer. Passing the fourth layer, which occupies a central position in the ventricular walls, and forms the boundary between the external and internal layers, the order of arrangement is reversed, and the fibres of the remaining layers, namely, five, six, and

[1] *Vide* Inaugural Prize Dissertation, by the Author, "On the Arrangement of the Cardiac Nerves, and their connection with the Cerebro-spinal and Sympathetic Systems in Mammalia," deposited in the University of Edinburgh Library, March 1861.
[2] "El. Phys.," tom. i. p. 351.
[3] "Cours de Physiologie," &c., tom. ii. p. 359.
[4] These dissections obtained for me Professor Goodsir's Senior Anatomy Gold Medal in the winter of 1858–59.
[5] "On the Arrangement of the Muscular Fibres in the Ventricles of the Vertebrate Heart, with Physiological Remarks," by the Author ; *Philosophical Transactions*, 1864.

seven, gradually return in an opposite direction, and in an inverse order, to the same relation to the vertical as that maintained by the fibres of the first external layer. The following diagram (Fig. 171) illustrates the point :—

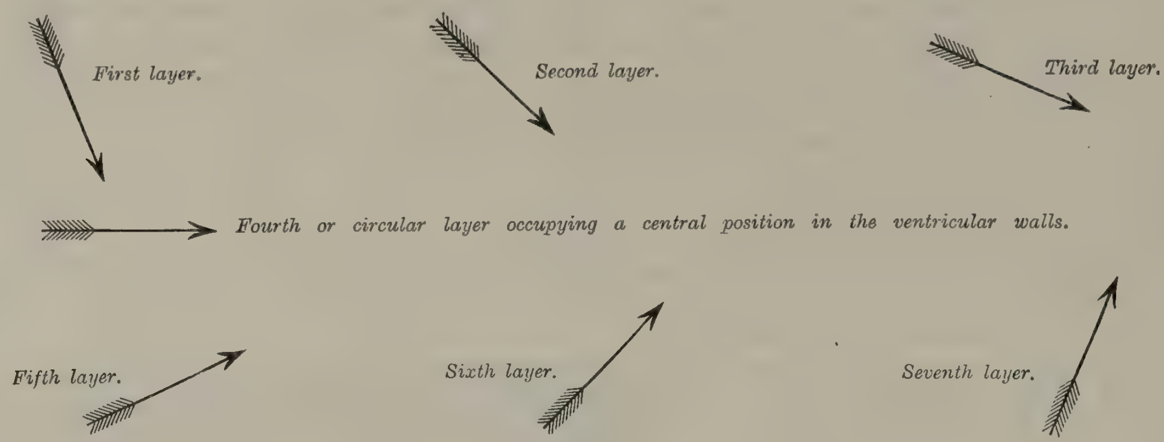


FIG. 171.

IV. The fibres composing the external and the internal layers are found at different depths from the surface, and from the fact of their pursuing opposite courses cross each other, the fibres of the first external and last internal layers crossing with a slight deviation from the vertical, as in the letter X; the succeeding external and internal layers, until the fourth or central layer, which is transverse, is reached, crossing at successively wider angles, as may be represented by an X placed horizontally so (Fig. 172) :—

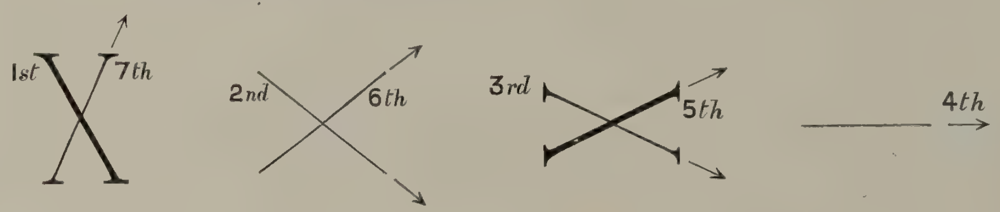


FIG. 172.

(*Vide* first eight figures of Plate xcvii., taken from photographs of actual dissections.)

V. The fibres composing corresponding external and internal layers, such as layers one and seven, two and six, &c., are continuous in the left ventricle at the left apex (Fig. 174, p. 509), and in the right ventricle in the track for the anterior coronary artery; the fibres of both ventricles being for the most part continuous likewise at the base [1] (Plate lxxxv., Fig. 5, p. 325).

VI. From this distribution of the fibres it follows that the first and seventh layers embrace in their convolutions those immediately beneath them, while these in turn embrace those next in succession, and so on until the central layer is reached—an arrangement which explains alike the rolling movements and powerful action of the ventricles. It also accounts for the spiral shape of the ventricular cavities, and the fact that the blood is literally wrung out of the ventricles during the systole.

VII. The fibres of the right and left ventricles occurring on the anterior and septal regions are to a certain extent independent of each other; whereas on the posterior region many of them are common to both ventricles; that is, the fibres pass from the one ventricle to the other—an arrangement which induced Winslow [2] to regard the heart as composed of two muscles enveloped in a third (Fig. 169, p. 506). It will be evident from this distribution of the fibres, that while the ventricles are for obvious reasons intimately united, they nevertheless admit of being readily separated (Fig. 173, p. 509).

VIII. If the hinge-like mass of fibres (common fibres) which unite the right ventricle to the left ventricle posteriorly be cut through, and the right ventricle with its portion of the septum detached, the left ventricle, which

[1] The late Dr. Duncan, jun., of Edinburgh, was aware of the fibres forming loops at the base, but seems to have had no knowledge of the continuity being occasioned by the union of the fibres of corresponding external and internal layers, or that these basal loops were prolongations of like loops formed by similar corresponding external and internal layers at the apex—a view which the author believes is here set forth for the first time.

[2] "Mémoires de l'Académie Royal des Sciences," 1711, p. 197.

consists of six sets of conical-shaped spiral fibres—three external and three internal sets with a central set between—will be found to be nearly as complete as it was before the separation took place. The right ventricle, and its share of the septum, on the other hand, will be found to consist of only conical-shaped spiral fragments of fibres, or at most of flattened rings—a circumstance which has induced me to regard the left ventricle as the typical or complete one, the right ventricle being a folding or duplication of a portion of the left (Fig. 169, p. 506).

IX. If the right ventricular wall be cut through immediately to the right of the track for the anterior and posterior coronary arteries, so as to detach the right ventricle without disturbing the septum, and the septum be regarded as forming part of the left ventricular wall, it will be seen that the fibres from the right side of the septum, at no great depth from the surface, together with the external fibres from the left ventricular wall generally, enter the left apex in two sets (Fig. 174); and if their course in the interior (Fig. 175, *m*, *n*) be traced, they are observed to extend in the direction of the left auriculo-ventricular opening, also in two sets; in other words, the left ventricle is bilateral. I wish particularly to direct attention to this bilateral distribution, as it has been hitherto overlooked, and furnishes the clue to the arrangement of the fibres of the left ventricle. The bilateral symmetry referred to extends also to the musculi papillares.

FIG. 173. FIG. 174. FIG. 175.

FIG. 173.—Right and left ventricles of mammal seen posteriorly (human). Shows how the fibres issue from the right and left auriculo-ventricular openings (*c*, *d*); the fibres from the left opening passing from the left ventricle (*e*) across (*f*) to the right ventricle (*g*). Of these some curve in a downward direction and disappear in the left apex; others curve round anteriorly and disappear in the anterior coronary groove. Compare with Fig. 169. *b*, Orifice of pulmonary artery (the Author, 1864).

FIG. 174.—Shows how the two sets of external fibres (*a*, *b*, *c*, *d*) of the left ventricle curve round and form a beautiful whorl prior to entering the left apex to become the two sets of internal fibres known as the musculi papillares, seen at *m*, *n* of Fig. 175. The fibres twist into each other at the apex in the same way that the segments of the mitral, tricuspid, and semilunar valves twist into each other at the base. Compare with Figs. 165 and 166, p. 499 (the Author, 1864).

FIG. 175.—Musculi papillares (*m*, *n*), chordæ tendineæ, and mitral valve (*v*, *v*) of left ventricle of deer. Shows how the musculi papillares, which are continuations of corresponding external fibres, are spiral in their nature, and how, when they alternately elongate and shorten, they alternately liberate and drag upon the segments of the mitral valve in a spiral manner; this, in conjunction with the blood, causing the segments to wedge and screw into each other, first in an upward and then in a downward direction (Fig. 165). The segments of the mitral and tricuspid valves rise and fall like diaphragms when the ventricles open and close. They alternately increase and diminish the cavities of the ventricles. Similar remarks may be made of the semilunar valves situated at the orifices of the pulmonary artery and aorta. Compare with Figs. 165 and 166 (the Author, 1864).

X. The double entrance of the fibres of the several layers at the left apex, and their exit in two portions from the auriculo-ventricular openings at the base, are regulated with almost mathematical precision; so that while the one set of fibres invariably enters the apex posteriorly, and issues from the auriculo-ventricular opening anteriorly, the other set as invariably enters the apex anteriorly and escapes from the auriculo-ventricular opening posteriorly. But for this disposition of the fibres, the apex and the base would have been lop-sided, instead of bilaterally symmetrical as they are.

XI. The two sets of fibres which constitute the superficial or first external layer of the left ventricle, and which enter the left apex in two separate portions or bundles, are for the most part continuous in the interior with the musculi papillares (Fig. 175, *m*, *n*), to the free ends of which the chordæ tendineæ are attached. The musculi papillares, as will be seen from this account, bear an important relation to the segments of the mitral valve (*v*, *v*), to which they are directly connected by tendinous bands. The musculi papillares from this circumstance merit a more particular description than that given of the other fibres.

On looking at the left auriculo-ventricular opening, the fibres of the first layer are seen to arise from the fibrous ring surrounding the aorta (Plate lxxxv., Fig. 5, *b*, p, 325), and from the auriculo-ventricular tendinous ring (*d*) in two divisions: the one division proceeding *from the anterior portions of the rings*, and winding in a spiral, nearly vertical, direction from before backwards, to converge and enter the apex *posteriorly* (Fig. 174, *b*); the other set proceeding *from the posterior portions of the rings*, and winding in a spiral direction from behind forwards, to converge and enter the apex *anteriorly* (Fig. 174, *d*). Having entered the apex, the two sets of external fibres are collected together, and form the musculi papillares and carneæ columnæ; the one set, namely, that which proceeded from the auriculo-ventricular orifice anteriorly and entered the apex posteriorly, curving round in a spiral direction from right to left upwards, and forming *the anterior musculus papillaris* (Fig. 175), *and the carneæ columnæ next to it;* the other set, which proceeded from the auriculo-ventricular orifice posteriorly, and entered the apex anteriorly, curving round in a corresponding spiral direction, and forming *the posterior musculus papillaris* (Fig. 175, *m*) *and adjoining carneæ columnæ*. As the external fibres converge on nearing the apex, so the

internal continuations of these fibres radiate towards the base; and hence the conical shape of the musculi papillares (*m*, *n*). I am particular in directing attention to the course and position of the musculi papillares, as they have always, though erroneously, been regarded as simply vertical columns, instead of vertical *spiral* columns. The necessity for insisting upon this distinction will appear more evident when I come to explain the influence exerted by these structures on the segments of the bicuspid valve. It is worthy of remark that while the left apex is closed by two sets of spiral fibres (Fig. 174, p. 509), the left auriculo-ventricular orifice is occluded during the systole by the two spiral flaps or segments constituting the bicuspid valve (Fig. 177, *m*, *n*). The bilateral arrangement, therefore, which obtains in all parts of the left ventricle and in the musculi papillares, extends also to the segments of the bicuspid valve, and hence its name. What has been said of the arrangement of the fibres in the left ventricle applies with slight modifications to the fibres of the right one; and many are of opinion (and I also incline to the belief) that the tricuspid valve (Fig. 165, p. 499) is in reality bicuspid in its nature. It is so in not a few cases, as shown at *g*, *h* of Fig. 177. The shape of the ventricular cavities of the heart of the mammal greatly influences the movements of the mitral and tricuspid valves, by moulding the blood into certain forms, and causing it to act in certain directions. A precise outline of the ventricular cavities was obtained by me by filling the ventricles with liquid wax or plaster of Paris, these substances when allowed to harden furnishing an accurate cast of the parts (*vide* Figs. 176–178).

FIG. 176.

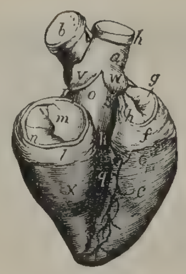


FIG. 177.

FIG. 178.

FIG. 176.—Photograph of a cast of left ventricle (*b*) and portion of right ventricle (*a*) of a deer, as taken in wax by the Author. Shows spiral nature of the left ventricular cavity,—the spiral courses or tracks of the musculi papillares (*x*, *y*), and how, between the musculi papillares, two spiral grooves (*j*, *q*) are found (they are spiral ridges in the cast), which conduct the blood to the segments of the mitral valve in spiral waves (the Author, 1864).

FIG. 177.—Photograph of a plaster of Paris cast of right and left ventricles of a zebra, seen posteriorly. Shows the mitral (*m*, *n*) and tricuspid (*g*, *h*) valves in action, and how the blood, when these are closed, assumes a conical form (*o*) for pushing aside the segments of the semilunar valves, and causing them to fall back into the sinuses of Valsalva (*v*, *w*). It also shows how the right ventricular cavity (*c*) curves round the left one (*x*), and how the pulmonary artery (*b*) and aorta (*h*) pursue different directions. *a*, Beginning of aorta; *l*, portion of left ventricle adhering to plaster of Paris; *f*, portion of right ventricle; *q*, spiral groove conducting to aorta (the Author, 1864).

FIG. 178.—Photograph of a plaster of Paris cast of right and left ventricles of a zebra, as seen from the left side. Shows infundibulum or conus arteriosus (*i*) of right ventricle, and analogous portion of left ventricle (*p*, *a*); also three prominences on each (*d*, *e*, *k*, *r*, *v*), corresponding to the sinuses of Valsalva. It also shows the double cone formed by the left ventricular cavity, the one apex pointing towards the apex of the heart (*j*), the other towards the aorta (*h*). *y*, Portion of anterior musculus papillaris adhering to plaster of Paris; *x*, portion of posterior musculus papillaris; *n*, spiral groove between musculi papillares corresponding to *q* of Fig. 176; *c*, portion of muscular wall of septum; *l*, portion of base of left ventricle; *z*, conical space of pulmonary artery where two of the segments of the semilunar valve join each other; *w*, point where coronary artery is given off; *b*, pulmonary artery; *h*, aorta (the Author, 1864).

The form of the left ventricular cavity is that of a double cone twisted upon itself (Fig. 176); the twist or spiral running from right to left of the spectator, and being especially well marked towards the apex.[1] The cone tapers towards the apex of the left ventricle (*y*), and also towards the base (*b*); and the direction of its spiral corresponds with the direction of the fibres of the carneæ columnæ and musculi papillares (Fig. 176, *x*, *y*). As the two spiral musculi papillares project into the ventricular cavity, it follows that between them two conical-shaped spiral depressions or grooves are found (Fig. 176, *q*, *j*). These grooves, which appear as spiral ridges in the cast, are unequal in size; the smaller one (Fig. 176, *j*) beginning at the right side of the apex, and winding in an upward spiral direction to terminate at the base of the external or left and smaller segment of the bicuspid valve (Fig. 177, *n*); the larger groove (Fig. 176, *q*) beginning at the left side of the apex, and pursuing a similar direction, to terminate at the base of the internal or right and larger segment (Fig. 177, *m*).

Running between the grooves in question, and corresponding to the septal aspect of the ventricular cavity, is yet a third groove larger than either of the others (Fig. 177, *q*). The third or remaining groove winds from the interior of the apex posteriorly, and conducts to the aorta (*a*), which is situated anteriorly. The importance of these grooves physiologically cannot be over-estimated, for I find that in them the blood is moulded into three spiral columns, and that during the systole the blood in the two lesser ones is forced in an upward direction in two spiral streams upon the under surfaces of the segments of the bicuspid valve, which are in this way progressively elevated towards the base and twisted and wedged into each other, until regurgitation is rendered impossible (Fig. 177, *m*, *n*). When the bicuspid valve is fairly closed, the blood is directed towards the third and largest groove, which, as has been explained, communicates with the aorta. The spiral action of the mitral valve, and the spiral motion communicated to the blood when projected from the heart, are due to the spiral arrangement of the musculi papillares and fibres composing the ventricle, as well as to the spiral shape of the left ventricular cavity.

[1] In this description the heart is supposed to be placed on its apex, with its posterior aspect towards the spectator.

What has been said of the conical shape of the left ventricular cavity and aorta applies, with slight alterations, to the right ventricular cavity and pulmonary artery (Figs. 177 and 178, *c*, *i*).

These points are further illustrated by Plates xcvii. and xcviii. ; the figures of which are selected from five plates of photographs by me appended to my memoir "On the Arrangement of the Muscular Fibres in the Ventricles of the Vertebrate Heart," published in the *Philosophical Transactions* in 1864.

The photographs in question represent over 100 of my dissections of the heart preserved in the Anatomical Museum of the University of Edinburgh, where they may be examined. They embrace those of the salmon, turbot, sunfish, shark, frog, tortoise, turtle, snake, alligator, swan, turkey, capercailzie, eagle, emu, dugong, porpoise, seal, lion, giraffe, camel, horse, ox, sheep, deer, man, &c. The photographs also represent a large number of original transparent models which enable the reader to trace the muscular fibres throughout their entire course.

As the arrangement of the muscular fibres in the ventricles of the heart of the mammal is to all intents and purposes identical, I have in the present instance delineated that in the sheep, calf, and deer. To those interested in elaborate, highly-finished dissections I would recommend the perusal of Appendix I. of the present work, where they will find an account of many new processes devised by me for the production of permanent spirit anatomical preparations.[1]

Plate xcvii. shows photographs of the seven different layers of spiral muscular fibres in the left ventricle of the heart of the sheep—how there are three external and three internal layers with a central layer between—how the external layers are each composed of two sets of spiral fibres which wind from the base to the apex of the ventricle and form left-handed spirals—how the internal layers are also composed of two sets of spiral fibres which wind from the apex to the base of the ventricle and form right-handed spirals—how the two sets of external and two sets of internal spiral fibres cross each other at increasing degrees of obliquity as the central layer is reached and form figure-of-8 loops—how the two sets of external spiral fibres involute or turn in at the apex, and the two sets of internal spiral fibres evolute or turn out at the base and are continuous with each other to produce perfect symmetry—how a certain proportion of the two sets of spiral fibres forming the superficial or first layer wind in at the apex and reappear as the two finger-like processes or musculi papillares seen in the interior of the ventricle, the free ends of which give off chordæ tendineæ which are attached to the margins and the posterior surfaces of the segments of the mitral valve and prevent their eversion during the systole—how the cavity of the ventricle is decidedly spiral in character—and how the right and left ventricles are separated from each other by a groove anteriorly (anterior coronary groove), but blended and united by muscular bands posteriorly.

Plate xcviii. illustrates the same points by the aid of transparent models.

The ventricles are constructed on the lattice girder principle, where stays and struts are employed in every direction to give the greatest amount of strength with the least possible material. As a matter of fact, the muscles of the ventricles are the most powerful muscles known. They work day and night, so long as life lasts, but the actual amount of work performed by them cannot be satisfactorily estimated because it varies in quantity and is more or less interrupted. It is, however, admitted by all to be incredibly great.

PLATE XCVII

The figures in this plate are accurate representations of photographs taken by the Author from dissections made by him in 1858 of the ventricles of the heart of man, the sheep, calf, deer, &c.[2] The majority of the figures give views of the several layers of spiral, looped, figure-of-8 muscular fibres as they occur in the left or typical ventricle of the heart when the ventricle is placed on its apex and its posterior wall dissected from without inwards. A certain number of the figures display a beautiful spiral whorl formed by the two sets of external and the two sets of internal fibres as they enter and leave the left apex. The internal become continuous with the two musculi papillares and carneæ columnæ in the interior of the ventricle. The remaining figures illustrate the spiral shape of the left ventricular cavity, and the relation of the right ventricle to the left ventricle.

FIG. 1.—Photograph of a posterior view of the left ventricle of a sheep, with the right ventricle detached. Shows the two sets of spiral muscular fibres which form the superficial or first layer. The fibres pursue a spiral, nearly vertical direction. *a*, Orifice of aorta; *b*, left auriculo-ventricular opening; *c*, line of separation of right ventricle; *e*, *e'*, spiral muscular fibres from anterior portion of septum and wall of ventricle which enter the apex posteriorly (*f*); *g*, *g'*, spiral muscular fibres from posterior portion of septum and wall of ventricle which enter the apex anteriorly (*h*). These two sets of spiral fibres wind from left to right, and are

[1] The appendix is headed "Anatomical Preparation-making as Devised and Practised by the Author at the University of Edinburgh and at the Hunterian Museum of the Royal College of Surgeons of England." It formed the subject of an article in the *Lancet* of dates November 23 and 30, 1901.

[2] These dissections and the descriptions and drawings thereof secured, as already stated, for the Author in the year indicated (1858-9), the Senior Anatomy Gold Medal of the University of Edinburgh, awarded by Professor John Goodsir. They formed the subject of the Croonian Lecture delivered to the Royal Society by the Author on the 19th of April 1860. (Vide *Proceedings of the Royal Society* of that date.)

seen entering the apex at *f* and *h* of Figs. 9 and 13. They are seen leaving the apex on the inside of the ventricle at *h* and *f* of Figs. 14 and 15. They form the two musculi papillares shown at *n*, *o* of Figs. 11 and 17. The musculi papillares occupy the spiral grooves *s*, *t* of Fig. 12, which represents a wax cast of the left ventricle of a deer. The two sets of spiral muscular fibres forming the first layer are continuous at the apex and partly at the base: the remainder arising from a tendinous band which surrounds the left auriculo-ventricular orifice. They are important from the fact that the greater number of them terminate in the two musculi papillares which give off the chordæ tendineæ which regulate the action of the mitral valve.

Fig. 2.—Photograph same as Fig. 1, but showing a deeper and more oblique layer (second layer). *b*, Left auriculo-ventricular orifice; *c*, line of separation of right ventricle; *i*, *i'*, spiral muscular fibres from septum and anterior wall of ventricle, which pursue a slightly oblique course and enter the apex (*j*) posteriorly; *k*, *k'*, spiral muscular fibres from posterior portion of septum and posterior wall, which pursue a slightly oblique course and enter the apex (*l*) anteriorly. These two sets of spiral fibres wind from left to right, and, for the most part, are continuous at the base as well as at the apex of the ventricle. They are seen entering the apex at *j*, *j'* and *l* of Fig. 10, and issuing from the apex internally at *h* and *f* of Figs. 14 and 15.

Fig. 3.—Photograph same as Fig. 2, but showing a deeper and still more oblique layer (third layer). *n*, *n'*, Very oblique spiral muscular fibres winding round on septum (*m*, *m'*) and entering the apex at *o*. They are arranged in two sets, and are continuous at the apex and base alike.

Fig. 4.—Photograph same as Fig. 3, but showing a deeper transverse or circular layer (fourth layer). The two sets of spiral fibres forming the fourth layer cross each other so obliquely as to present a circular appearance. In reality, and strictly speaking, there is no circular layer in the left ventricle. The fourth layer is composed of loops of very oblique figure-of-8 spiral fibres. It forms the boundary between the external and internal layers, and when it is removed the spiral fibres which form the internal layers are exposed. These reverse their direction, and gradually change from a very oblique to a nearly vertical course. In the external layers the spiral muscular fibres pursue a more and more oblique direction. In the internal layers, on the other hand, they pursue a more and more vertical one. The spiral fibres of the external layers cross the spiral fibres of the internal layers at ever-increasing degrees of obliquity until the central or transverse layer is reached. Thus the spiral fibres of Fig. 1 cross the spiral fibres of Fig. 7 at acute angles; those of Figs. 2 and 6 at obtuse angles; and those of Figs. 3 and 5 at still more obtuse angles. *p*, *p*, *p'*, Very oblique or transverse spiral muscular fibres winding round central portion of ventricle and entering the apex at *q*. These fibres are seen to make a distinct turn round the apex. A corresponding and similar set wind in an opposite direction and enter the apex at a point opposite to *q*. The fibres of the fourth layer are continuous upon themselves both at the apex and base of the ventricle.

Fig. 5.—Photograph showing a still deeper layer (layer five). The fifth layer is the first of the internal layers. The direction of the muscular fibres is now changed. Hitherto the fibres wound from left to right and from the base to the apex of the ventricle; now they wind from right to left and from the apex to the base. Everything is reversed. *r*, *r'*, Spiral muscular fibres winding very obliquely from right to left and from below upwards. These fibres are continuous with corresponding external fibres at the apex and base of the ventricle. They are seen involuting and entering the apex of the ventricle at *s* and evoluting and leaving the base of the ventricle at *n* and *p*. The fifth layer is the counterpart of the third layer as seen at Fig. 3.

Fig. 6.—Photograph same as Fig. 5, but showing a deeper layer (layer six). *s*, *s'*, Spiral muscular fibres pursuing a less oblique course than the fibres in Fig. 5. The fibres in this layer wind from right to left and from below upwards, and like those of the fifth layer are continuous with corresponding external fibres at the apex and base of the ventricle. A portion of the continuous fibres at the base is seen at *r* (compare with *r* of Fig. 5). Portions of the external layers 1, 2, and 3 are seen at *g*, *k*, *n'*. The dart marked *n'* shows the manner in which the internal fibres evolute and turn out or over at the base. The sixth layer is the counterpart of the second layer as seen at Fig. 2.

Fig. 7.—Photograph same as Fig. 6, but showing a deeper layer (layer seven). *t*, *t'*, Two sets of spiral muscular fibres pursuing a less oblique course than the fibres in Fig. 6. The fibres in this layer wind from right to left and from below upwards. Like those of the sixth and fifth layers, they are continuous with corresponding external fibres at the apex and base of the ventricle. The fibres marked *t* are seen evoluting and folding out at the base at *g*. The two sets of fibres (*t*, *t'*) are the same as those seen at *h*, *f*, of Figs. 14 and 15. The seventh and most internal layer is the counterpart of the first or most external layer, as seen in Fig. 1.

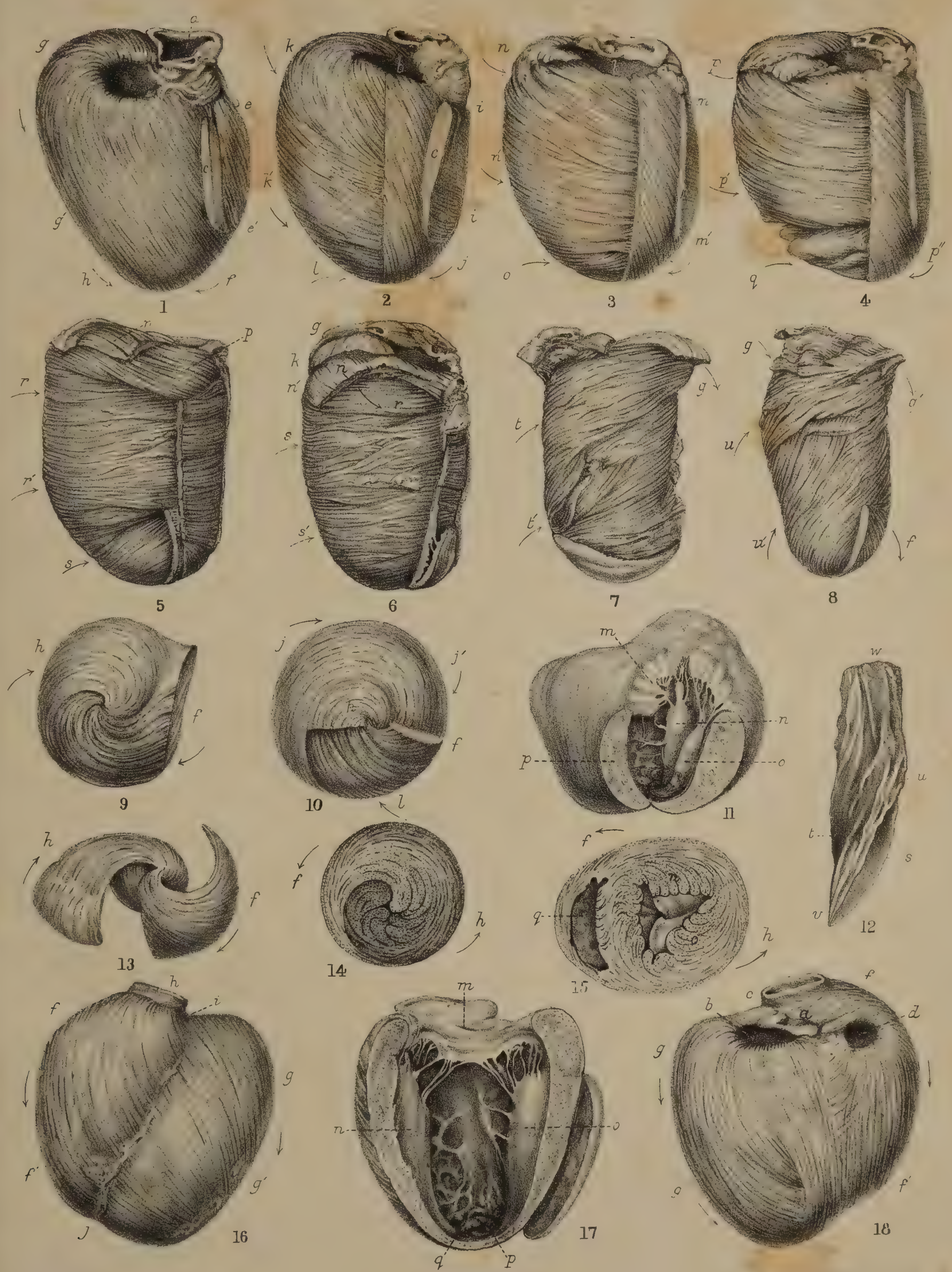
Fig. 8.—Photograph giving a deeper dissection of layer seven (Fig. 7). The deeper dissection is necessary to expose the tracks and the positions occupied by the two musculi papillares. *u*, *u'*, Two sets of spiral muscular fibres found in immediate proximity to the cavity of the ventricle. These fibres pursue a spiral vertical direction. Those marked *u'* form part of the posterior musculus papillaris: a corresponding set of fibres on the opposite side of the ventricle forming part of the anterior musculus papillaris. The fibres (other than those forming the musculi papillares) evolute or turn out at *g*, *g'* (base) and involute or turn in at *f* (apex). The two musculi papillares may be said to evolute through their chordæ tendineæ and the segments of the mitral valve. The two spiral musculi papillares referred to are seen at *n*, *o* of Figs. 11 and 17. The chordæ tendineæ and the segments of the mitral valve are seen at *m* of the same figures. The spiral tracks made by the two musculi papillares are given at *s*, *t* of Fig. 12.

Fig. 9.—Photograph of a dissection by the Author of the left ventricle of a sheep's heart, showing the posterior surface and apex of the left ventricle. The left ventricle of the heart of the mammal is composed of two sets of superficial spiral fibres (*f* and *h*). These fibres on entering the apex form a most exquisite whorl. Compare also with Fig. 8 of Plate xcviii. It is these two sets of fibres which are chiefly concerned in forming the two musculi papillares. The whorl formed by the two sets of spiral muscular fibres of the left ventricle of the heart of the sheep is quite as distinct in the left ventricle of the human heart. It very closely resembles in appearance that of several shells (see Plate xiii., Fig. 1, E, F, and G, p. 28). It also resembles certain spiral nebulæ (Plate viii., Fig. 4, p. 17).

Fig. 10.—Photograph same as Fig. 9, but showing a deeper dissection. Here the two sets of spiral muscular fibres forming the second external layer (Fig. 2) involute and enter the left apex. *f*, *k*, The two sets of spiral superficial fibres forming the first layer entering the left apex; *j*, *j'*, the two sets of spiral fibres forming the deeper second layer entering the left apex. The orifice of the left apex becomes larger as the fibres of the several external and internal layers are removed. The spiral muscular fibres which are seen turning in or involuting at Figs. 9, 10, and 13 are seen evoluting or turning out at Figs. 11, 14, 15, and 17.

Fig. 11.—Photograph of a dissection by the Author of the left ventricle of the heart of a deer laid open to show the carneæ columnæ, musculi papillares, chordæ tendineæ and mitral valve *in situ*. *o*, *n*, Spiral anterior and posterior musculi papillares twisting out of the interior of the left apex. These structures are nearly straight. Certain tendinous bands (chordæ tendineæ) issue from their summits and are inserted into the segments of the mitral valve (*m*). They also send muscular and tendinous processes

PLATE XCVII.



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to the irregular fretted surface (carneæ columnæ) of the interior of the ventricle. The musculi papillares exercise a direct influence on the action of the mitral valve, which they assist in opening and closing by beautiful spiral movements. They also, by projecting spirally into the cavity of the left ventricle, convert that chamber into an exquisitely spiral one. A wax cast of the chamber in question is given at Fig. 12. *p*, Section of muscular wall of left ventricle. The muscular wall is exceedingly thin at the apex, to admit of a free twisting movement when the ventricle is opening and closing and propelling the blood; the apex forming as it were a living agile hinge.

FIG. 12.—Wax cast of the cavity of the left ventricle of a deer. This cast gives the exact shape assumed by the blood in the left ventricular cavity prior to its being ejected into the aorta during systole or when the ventricles contract. The blood is made to gyrate in the aorta as a rifle bullet is made to gyrate within the barrel of the weapon when it is fired off. The left ventricular cavity tapers slightly towards the base of the ventricle and markedly towards the apex. It forms a beautiful spiral, which runs from right to left of the spectator. I have obtained similar graceful spiral casts from the right and left ventricular cavities of the human heart by the employment of liquid plaster of Paris. They are figured in the text. *v*, Apex of cavity; *w*, base of cavity; *u*, *v*, well-marked projecting spiral ridge running from right to left. This spiral projection represents a spiral groove in the ventricular cavity. *s*, *t*, Two hollow spiral tracks corresponding with the two spiral projections caused by the presence of the anterior and posterior musculi papillares (Figs. 11 and 17, *n*, *o*).

FIG. 13.—Photograph of apex of the left ventricle of the heart of a sheep, with the two sets of spiral muscular fibres opened out or unravelled. *f*, *h*, The two sets of spiral muscular fibres which form the superficial or first external layer seen at *e*, *e′*, *g*, *g′* of Fig. 1 involuting and entering the left apex in a graceful whorl.

FIG. 14.—Photograph of a section of the apex of the left ventricle of the heart of a deer. *h*, *f*, Two sets of spiral fibres, similar to those seen at *f*, *h* of Fig. 13, evoluting and turning or twisting out of the interior of the left apex. These two sets of spiral muscular fibres form an exquisite whorl. They correspond with the muscular fibres *h*, *f* of Fig. 15. Figs. 9, 10, 13, and 14 resemble the beautiful vortices made by nebulæ, by shells, and many plant structures. The two sets of spiral muscular fibres completely occlude the left apex during the systole.

FIG. 15.—Photograph of a section of the right and left apices of the ventricles of the heart of a sheep. *h*, *f*, Two sets of spiral muscular fibres evoluting and twisting out of the interior of the left ventricle. They are continuations of the two sets of external spiral muscular fibres marked *f*, *h* in Figs. 9 and 13. They are seen on the body of the left ventricle at *e*, *e′*, *g*, *g′* of Fig. 1. *q*, Cavity of apex of right ventricle. The spirals seen in this figure are the reverse of those seen at Figs. 13 and 14.

FIG. 16.—Photograph of an anterior view of the spiral muscular fibres in the right and left ventricles of the heart of a sheep. *f*, *f′*, Superficial spiral muscular fibres of the right ventricle. These fibres dip into the sulcus (*i*, *j*) and assist in forming the septum or partition between the ventricles. *g*, *g′*, Spiral muscular fibres forming part of the septum ventriculorum and issuing from the sulcus (*i*, *j*) to form the superficial layer of the left ventricle anteriorly. The spiral muscular fibres forming the anterior superficial layer in the right and left ventricles are non-continuous; that is, they dip into and issue from the sulcus (*i*, *j*). The spiral muscular fibres forming the posterior superficial layer of the right and left ventricles, on the other hand, are continuous, as seen in Fig. 18. In other words, certain of the spiral muscular fibres from the left ventricle (*g*, *g′*) sweep across to the right ventricle (*f*, *f′*). This apparent anomaly is explained by supposing that the right and left ventricles were formed originally from one conical muscular chamber by pushing in the anterior wall of the chamber until it touched the posterior one, as represented at Figs. 13 and 14 of Plate xcviii., which see. *h*, Root of pulmonary artery.

FIG. 17.—Photograph of a dissection by the Author of the left ventricle of calf's heart, opened laterally to show the carneæ columnæ and the anterior and posterior spiral musculi papillares with their chordæ tendineæ and mitral valve *in situ*. *o*, Spiral anterior musculus papillaris, curving out of the posterior portion of the interior of the left apex (*p*); *r*, spiral posterior musculus papillaris curving out of the anterior portion of the interior of the left apex (*q*). The terminal portions (*p*, *q*) of the anterior and posterior musculi papillares form an elegant double spiral whorl just within the apex. The two sets of spiral muscular fibres forming the whorl curve into and embrace each other. Compare with *e*, *f* of Fig. 11 of Plate xcviii. *m*, Segment of the mitral valve attached at its free margins by chordæ tendineæ to the anterior and posterior musculi papillares (*o*, *n*).

FIG. 18.—Photograph of a posterior view of the right and left ventricles of the heart of a sheep, showing how the spiral superficial fibres from the left ventricle (*g*, *g′*) are continuous on the right ventricle (*f*, *f′*). *a*, Orifice of aorta; *b*, left auriculo-ventricular orifice; *c*, orifice of pulmonary artery; *d*, right auriculo-ventricular orifice (the Author).

PLATE XCVIII

The figures in this plate are taken from photographs and drawings by the Author of dissections and transparent models made by him in the year 1858, to illustrate the spiral arrangements of the muscular fibres in the ventricles of the heart of the mammal; especially the left ventricle, which he regards as the complete and typical one. The transparent models are composed of sheets of white coarse net, three times as long as they are broad, through which dark threads of Berlin wool are drawn in straight lines at regular intervals. In order to make an artificial transparent left ventricle, two sheets are employed, one of the sheets being superimposed and placed at a slight angle to the other. The sheets are arranged on a table so that the threads of wool run across the operator, who seizes the sheets by the right-hand off corners and rolls them obliquely towards himself in the direction of the left-hand near corners to form a cone similar to that formed by the left ventricle itself. When this is done, and one and three-quarters of a turn made, the sheets display in the most remarkable manner all the peculiarities in the arrangement of the muscular fibres of the left ventricle: they in fact produce a transparent left ventricle, in which the seven different layers (three external, a fourth or central, and three internal), each composed of two portions and having different directions, are represented. The threads of the sheets, when the cone is placed on its apex, are seen to wind spirally in the three external layers in a direction from left to right downwards, and to become more

oblique as the central layer is approached; those of the three internal layers winding spirally in a direction from right to left upwards and becoming more vertical as the central layer is departed from. The threads of the external layers form two sets of left-handed spirals; those of the internal layers two sets of right-handed spirals. The threads forming the external layers are also seen to wind round and involute or turn in at the apex in two sets; those forming the internal layers winding round the interior and evoluting or turning out at the base in two sets. The threads are thus continuous at both apex and base, and form during their convolutions a beautiful double series of figure-of-8 loops. If the right-hand off corners of the two sheets, before being rolled, have elongated triangular portions marked off by dark threads to represent the two musculi papillares, these portions, when the sheets are rolled up, will be seen to wind out spirally from within, and to occupy the exact positions occupied by the actual musculi papillares of the left ventricle. The involution of the threads at the apex is produced by the rolling process, and the evolution of the threads at the base is produced by folding out the net containing the threads so as to cause the several internal layers to meet corresponding external layers. In this way the continuity of the threads at the apex and base is assured.

The sheets of net prepared and treated as described give what may be regarded as a mathematical demonstration of the construction of the left ventricle, exceedingly simple in principle but wonderfully complicated in detail. The Gordian knot in anatomy, which the structure of the left ventricle has for centuries constituted, may now be regarded as untied.

Without dogmatising as to how the left ventricle is developed *in utero*, there cannot be a doubt that it is built up on the most scientific principles, and is a marvel of design: its muscular fibres crossing and recrossing in every direction to produce the greatest amount of strength with the least possible material.

It may be taken for granted that, in growing, the spiral muscular fibres of the left ventricle are deposited in layers: the fibres of the external and internal layers overlapping externally and internally and equilibrating each other according to a mathematical law which is never departed from; the external and internal layers growing at or nearly at the same time in fulfilment of a definite and predetermined plan. The left ventricle is certainly not a chance production, neither is it produced by irritability, stimulation, or environment. The care bestowed on its construction is fully justified considering the momentous nature of the work performed by it. In reality it propels the entire blood through the system, and is at once the most powerful, involved, and important muscle known.

The left ventricle, as far as completeness of design, beauty, and utility are concerned, will more than hold its own with all other organic structures. It combines the graceful curves of the shell, of the spiral horn, and of the climbing plant in quite a remarkable manner. The reader may readily confirm what is here stated by cutting two sheets transversely from a newspaper of the dimensions indicated above; the lines of print being made to represent the dark threads of Berlin wool.

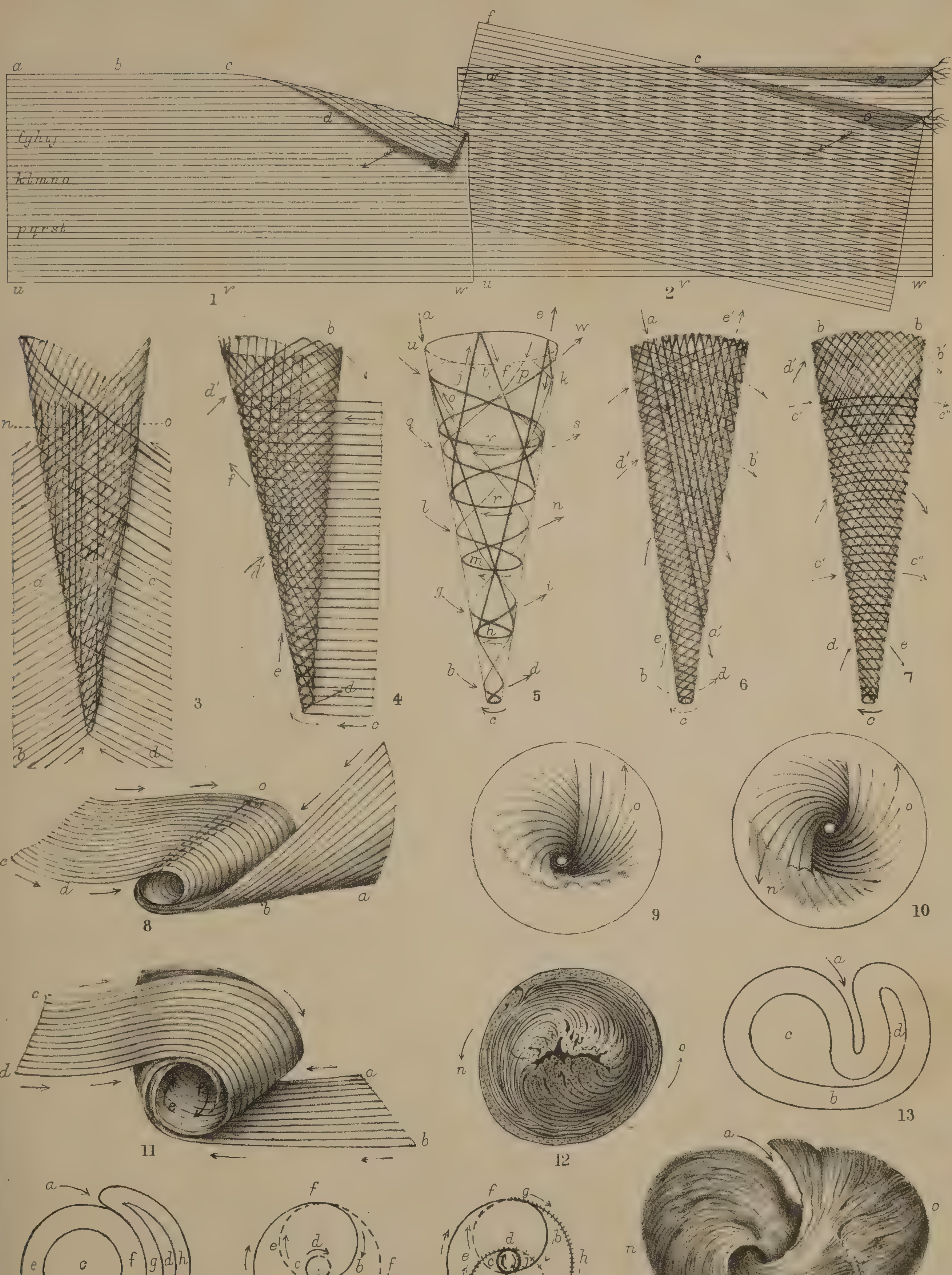
By arranging and rolling up the printed sheets as directed, the reader will construct in a few seconds what is practically a complete left ventricle, both as regards principle and detail. At the outset it will be best for the sake of simplicity to employ only one sheet, in which case it should be rolled up three and a half turns to give the seven layers. The single sheet is more easily manipulated and understood, and by doubling the number of turns made by it the same result is practically obtained as with the double sheets rolled up one and three-quarter turns. The double sheets rolled up one and three-quarter turns make a symmetrical artificial left ventricle in all respects resembling the natural or real left ventricle.

FIG. 1.—Sheet of net with parallel threads of dark wool drawn through it at regular intervals. *a*, *b*, *c*, Anterior margin of sheet of net with a triangular portion of it (*d*, *e*) rolled up in the direction of the arrow; *f*, *g*, *h*, *i*, *j*, a single thread of wool, the spiral course of which (when the net is rolled up obliquely into a cone) is traced at Fig. 5 (*vide* same letters); *k*, *l*, *m*, *n*, *o*, another thread similarly traced in Fig. 5, by the same letters; *p*, *q*, *r*, *s*, *t*, a third thread similarly traced in Fig. 5; *u*, *v*, *w*, the posterior margin of the sheet of net. The threads when coiled up form figure-of-8 loops (*vide* Fig. 5).

FIG. 2.—Two sheets of net, the one superimposed and placed at an acute angle, with triangular portions of the sheets marked off with dark threads to represent the musculi papillares. *f*, Anterior margin of superimposed sheet of net. The dark triangular part marked *o* represents (when the sheets are rolled up into a cone) the anterior musculus papillaris. *a*, *b*, *u*, *v*, *w*, Anterior and posterior margins of lower sheet of net. The dark triangular portion of the lower sheet marked *n* represents (when the sheets are rolled up into a cone) the posterior musculus papillaris. The two sheets of net are rolled into a cone in the direction of the arrow at *o*. By employing two sheets of net the bilateral symmetry of the left ventricle is accurately imitated, and the several spiral threads representing the spiral muscular fibres of that ventricle are seen to enter the apex and leave the base of the cone formed by the two sheets of net always in two sets (Fig. 11, *e*, *f*; and Fig. 10, *n*, *o*).

FIG. 3.—Two sheets of net partially rolled up into a symmetrical cone to show how the threads representing the spiral external muscular fibres of the left ventricle involute or enter the apex of the cone in two sets; also how in the interior of the cone there are two sets of spiral, nearly straight threads, which correspond with the spiral anterior and posterior musculi papillares of the left ventricles. *a*, *b*, Sheet of net, the lower marginal threads of which enter the apex of the cone anteriorly. They pursue a spiral, nearly vertical course in the interior of the cone, and are seen posteriorly as a triangular layer (*o*). They correspond with

PLATE XCVIII.



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the spiral posterior musculus papillaris of the left ventricle (compare with *n* of Figs. 11 and 17, Plate xcvii.). *c*, *d*, Sheet of net, the lower marginal threads of which enter the apex of the cone posteriorly. They pursue a spiral nearly vertical course in the interior of the cone and are seen anteriorly as a triangular layer (*n*). They correspond with the spiral musculus papillaris (compare with Figs. 11 and 17, Plate xcvii.). The same arrangement is seen at *o*, *n* of Fig. 10 and *f*, *e* of Fig. 11.

FIG. 4.—A single sheet of net rolled up one and three-quarter turns, showing in detail a portion of the fourth or central so-called circular layer; how the internal layers are formed, and how the spiral threads which represent the spiral muscular fibres of the left ventricles turn into or enter the apex and turn out or leave the base. *c*, Portion of sheet forming the transverse or central layer. The threads involute or enter the apex spirally (*vide* arrows *d*, *e*), and wind round inside the cone to form two internal spiral oblique layers (*e* and *d′*, *d′*). The marginal threads of the innermost layer (*e*) correspond with the posterior musculus papillaris (see Plate xcvii., Fig. 11, *n*, and Fig. 17, *o*). The spiral oblique threads marked *d′*, *d′*, when made to evolute or turn out at the base by a simple process of folding as at *b*, are found to correspond in direction with other spiral oblique threads on the external portion of the cone, namely, those marked *f*. The threads in this way become continuous both at the apex and the base of the cone, as in the left ventricle itself.

FIG. 5.—Sheet of net with dark threads of wool drawn through it at wide intervals rolled up into a cone one and three-quarter turns; the cone being placed upon its apex. Shows how threads, originally of the same length, make fewer spiral turns and larger figure-of-8 loops from winding round wider portions of the cone. It also shows how the apex of the cone may be enlarged by removing in succession the threads which make the greatest number of spiral turns, and which, curiously enough, overlap the threads which make the least number of spiral turns and the larger figure-of-8 loops. The threads in this figure correspond with the threads in Fig. 1, bearing similar letters. Their entire course can be traced in every part of the ventricular wall. Thus the thread marked *a*, *b*, *c*, *d*, *e* can be traced from beginning to finish, and so of the others marked *f*, *g*, *h*, *i*, *j*; *k*, *l*, *m*, *n*, *o*; *p*, *q*, *r*, *s*, *t*, and *u*, *v*, *w* respectively. The darts indicate the courses pursued by the several threads.

FIGS. 6 and 7.—Anterior and posterior views of cones produced by rolling single sheets of net (as in Fig. 1) obliquely upon themselves one and three-quarter turns. The one cone (Fig. 7) is placed within the other (Fig. 6) to give the seven layers. This plan is adopted to avoid too great complexity. A similar result is obtained by rolling a single sheet of net three and a-half turns. In the cone (Fig. 7) that portion of the sheet which forms the base (*b*, *b*) has been folded in an outward direction; an operation which causes the threads forming the internal layers of the sheet to become parallel with those forming the external layers of the sheet. These figures show how, by portions of the sheet overlapping other portions, the seven layers of the ventricle are produced; the threads composing these layers having different directions. If the cone (Fig. 7) be placed within the cone (Fig. 6), and the layers of the two cones combined, the seven layers, each having different directions, can readily be made out. They show how the layers or overlappings are confined to different regions or localities as in the left ventricle, and satisfactorily account for the ventricular wall tapering towards the base and the apex respectively. The overlapping of the several layers in the actual left ventricle is seen at Plate xcvii., Figs. 1 to 8 inclusive. The tapering of the wall of the left ventricle towards the base and apex is shown at Plate xcvii., Fig. 11, and also at Fig. 17 of same plate.

FIG. 6.—*a*, *a′*, Threads winding in a spiral, nearly vertical direction from left to right downwards, and forming the first external layer (compare with the muscular fibre marked *g*, *g′*; *e*, *e′* of Fig. 1, Plate xcvii.). These threads are continuous at the apex with the threads forming the seventh or corresponding internal layer, *e*, *e′* (compare with the muscular fibres marked *t*, *t′* and *u*, *u′* of Figs. 7 and 8, Plate xcvii.).

FIG. 7.—*b*, *b*, *b′*, Threads winding in a spiral oblique direction from left to right downwards and forming the second layer. These threads turn spirally upon themselves at the apex at *e*, *c*, *d* (compare with the muscular fibres marked *k*, *k′* and *i*, *i′* of Fig. 2, Plate xcvii.). These threads are continuous at the apex and the base with the threads forming the sixth or corresponding internal layer *d*, *d′* (compare with the muscular fibres marked *s*, *s′*, of Fig. 6, Plate xcvii.).

FIG. 8.—*b*, *b′*, Threads winding in a spiral very oblique direction from left to right downwards and forming the third layer. (Compare with the muscular fibres marked *n*, *n′* of Fig. 3, Plate xcvii.). These threads are continuous at the apex and the base with the threads forming the fifth or corresponding internal layer *d*, *d′* (compare with the muscular fibres marked *r*, *r′* of Fig. 5, Plate xcvii.).

FIG. 7.—*c*, *c′*, *c′*, Threads winding in a circular or transverse direction and forming the fourth or central layer, which divides the three external from the three internal layers (compare with the muscular fibres marked *p*, *p′* of Fig. 4, Plate xcvii.). It is in this layer that the three external layers terminate and the three internal ones begin.

FIG. 8.—Symmetrical cone produced by the rolling of two sheets of net (*a*, *b*, *c*, *d*) within each other. Shows position and track of the anterior musculus papillaris, *o* (compare with *o* of Figs. 9 and 10).

FIG. 9.—Interior of a single sheet of net rolled up into a cone as explained. Shows how the spiral almost vertical direction pursued by the anterior musculus papillaris is exactly imitated by the threads of wool (compare with *o* of Figs. 11 and 17 of Plate xcvii.).

FIG. 10.—Interior of a symmetrical cone produced by rolling two sheets of net within each other. Shows how the symmetry of the cone is maintained by the one sheet winding from right to left (*n*); the other winding from left to right (*o*). The margins of the sheets with their radiating threads indicate the positions of the anterior and posterior musculi papillares respectively (compare the radiating threads of the sheets with the two sets of muscular fibres marked *n* and *o* of Fig. 12 of this plate, which gives a transverse section of the left ventricle of the heart of a deer; compare also with *n*, *o*, of Figs. 11 and 15 of Plate xcvii.).

FIG. 11.—Two sheets of net rolled within each other and then permitted to spring open. Shows symmetry of cone, especially at apex. *a*, *b*, Sheet winding from right to left and entering apex of cone at *f*; *c*, *d*, sheet winding from left to right and entering apex of cone at *e*. The marginal threads *b* and *d* of the sheets which enter the apex of the cone at *f* and *e* represent the beginnings of the anterior and posterior musculi papillares (compare with *o*, *n* of Fig. 12, and with *f*, *h* of Figs. 14 and 15 of Plate xcvii.).

FIG. 12.—Section of the apex of the left ventricle of the heart of a deer. Shows how the spiral muscular fibres near the apex are arranged in two sets in a beautiful whorl. The two symmetrical sets of fibres *o*, *n* curve into and wind round each other, and,

during the systole, completely occlude the apical portion of the left ventricular cavity. These two sets of fibres are the anterior and posterior musculi papillares cut across. They are composed chiefly of the first and seventh and second and sixth layers of the left ventricle (compare with *o*, *n* of Fig. 10).

FIG. 13.—Shows how by pushing in the anterior wall (*a*) of the typical or left ventricle, in imitation of the constructive process in the embryo, a double septum unattached posteriorly (*b*) is produced; this septum dividing the ventricle into two—a right or rudimentary ventricle (*d*), and a left or more complete one (*c*). It also shows how the fibres may be continuous or common to both ventricles posteriorly (*b*), while anteriorly (*a*) they dip in at the track for the anterior coronary artery, and are to a certain extent independent of each other (compare with Figs. 16 and 18 of Plate xcvii.).

FIG. 14.—Shows how the posterior fold of the septal duplicature (*a*), by passing through the posterior wall (*b*) until the central layer is reached, completely isolates the right ventricle (*d*) from the left (*c*), and how, by the atrophy of the right ventricular wall (*h*) and its share of the septum (*g*) after birth to half their original dimensions, the right ventricular wall (*h*) is reduced to half the thickness of the left ventricular wall (*c*); while the septum (*f*, *g*) is three times as thick as the wall of the right ventricle, and a third thicker than the wall of the left ventricle. In a transverse section of the ventricles of the deer, the septum ventriculorum is found to be considerably thicker than the wall of the left ventricle, if the musculi papillares be excluded.

FIG. 15.—Represents the course pursued by a single thread or muscular fibre; how it winds from the base to the apex in one direction, and from the apex to the base in another and opposite direction, so as to return to the point from which it set out. It also shows how the thread or fibre is continuous towards the apex and the base. *a*, *b*, *c*, External portion of the thread or fibre winding from the base to the apex of the left ventricle; *d*, point at which the thread or fibre enters the apex and alters its direction; *e*, *ff'*, internal portion of the thread or fibre winding from the apex to the base, to return to the point of departure (*a*).

FIG. 16.—Represents the course pursued by two threads or muscular fibres, each of which is similar to that seen at Fig. 15. In this figure the external portion of one of the threads or fibres (*a*, *b*, *c*) winds from behind forwards and enters the apex anteriorly (*d*); the external portion of the other thread or fibre (*g*, *h*, *i*, *j*) winding from before backwards and entering the apex posteriorly (*k*). The external portions of the threads or fibres are therefore symmetrically disposed with reference to each other. Similar remarks apply to the internal continuations of these threads or fibres (*e*, *f*, and *l*, *m*), which are only partially seen. The external and internal portions of the threads or fibres are continuous, and when seen from above appear to form complete circles. Perfect bilateral symmetry is the result.

FIG. 17.—Photograph of a sheep's heart separated by the Author (*a*, *b*) into its bilateral elements. *o*, Anterior muscular fibres entering the left apex posteriorly; *n*, posterior muscular fibres entering the left apex anteriorly (compare with Fig. 11). The internal continuations of these two sets of fibres are seen in the threads *n*, *o* of Fig. 10, and in *n*, *o* of Figs. 11 and 17, Plate xcvii. (the Author).

PLATE XCIX

The plate of the valves of the vascular system in vertebrata naturally follows Plates xcvii. and xcviii., delineating the arrangement of the muscular fibres in the left or typical ventricle of the heart. It reproduces the fine curves and whorls which characterise the several parts of the left ventricle in the heart of the man, the sheep, horse, &c. The whorls are also seen in the spiral shell (Plate xiii.. Fig. 1, F, G, p. 28), spiral nebulæ (Plate viii., p. 17), and other arrangements. Plate xcix. also shows the bilateral nature and symmetry of the bicuspid or mitral valve.

FIG. 1.—External jugular vein of the horse inverted and distended with liquid plaster of Paris. *a*, *b*, *c*, Venous valve composed of three cusps or segments; *d*, *e*, venous valve composed of two segments.

FIG. 2.—External jugular vein of the horse opened; shows valve consisting of two cusps or segments. *a*, *b*, Interior of cusps with dilatations (*d*, *e*) corresponding to the sinuses of Valsalva in the aorta and pulmonary artery (compare with *c* of Figs. 24 and 30); *e*, junction of the two segments.

FIG. 3.—Same as Fig. 2. Shows attachment (*c*) of segments of valve (*a*, *b*) to interior of vein. The segments of the venous valves are very ample and readily occlude the veins.

FIG. 4.—Portion of human femoral vein distended with liquid plaster of Paris. Shows dilatations (*e*, *d*) behind or outside the cusps of the valves closed at *e*.

FIG. 5.—Shows venous valve of vein of horse, consisting of two cusps or segments (*a*, *b*) closed or in action; the closure being effected by liquid plaster of Paris. *c*, *d*, Swellings of vein behind the segments (compare with *c*, *d*, of Fig. 4).

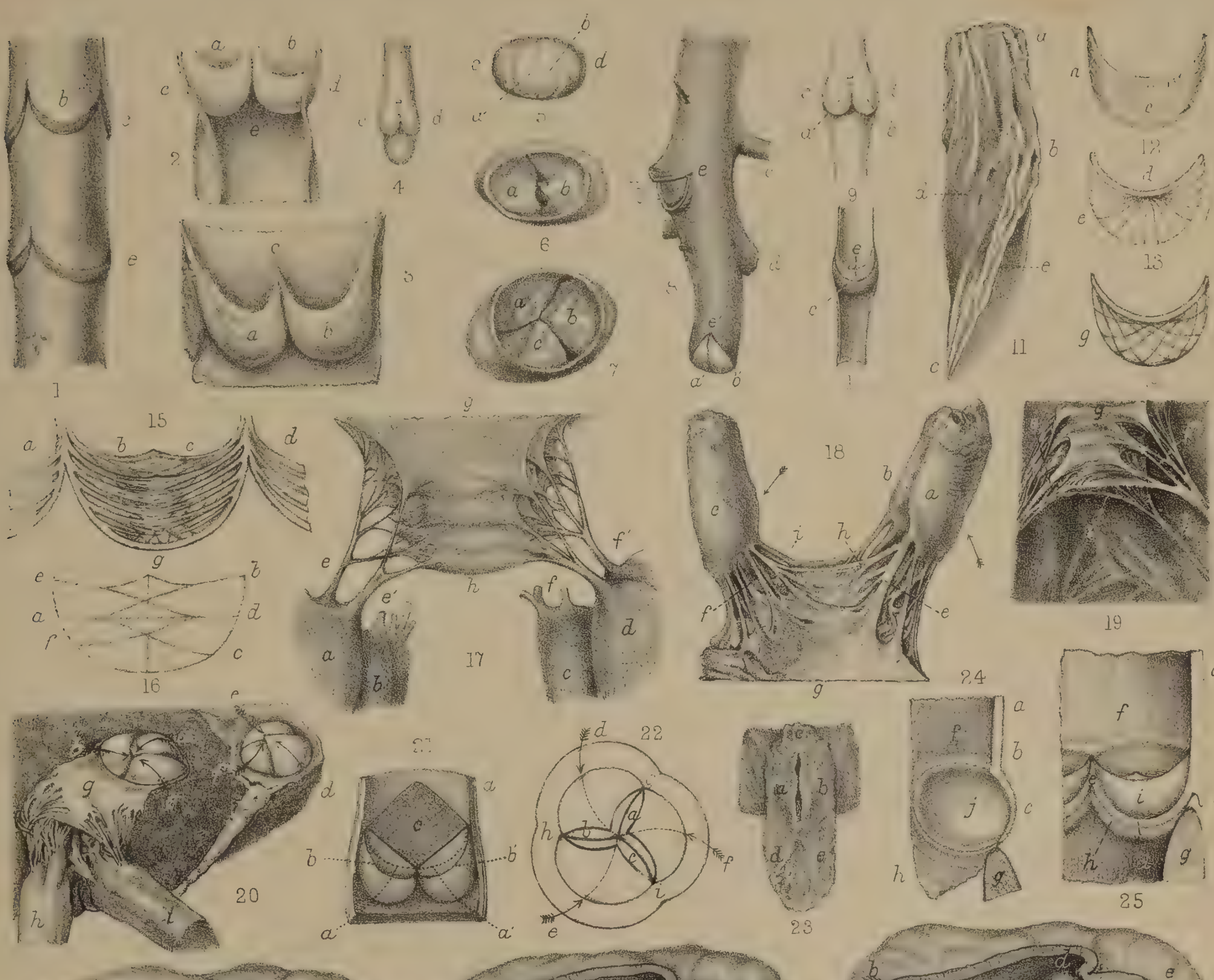
FIG. 6.—Venous valve of two segments (*a*, *b*) from vein of horse partly closed.

FIG. 7.—Venous valve from external jugular vein of horse, consisting of three cusps or segments (*a*, *b*, *c*) nearly closed.

FIG. 8.—Portion of femoral vein distended with liquid plaster of Paris. Shows venous valves in action, where a large vein enters the main trunk (*a*, *b*, *e*) and in the main trunk itself (*a'*, *b'*, *e'*). *c*, *d*, Small veins entering main trunk.

FIG. 9.—Vertical section of vein distended and venous valve closed with liquid plaster of Paris. *a*, *b*, Cusps or segments of valve; *e*, union of cusps in mesial plane of vein; *c*, *d*, dilatations outside cusps. The latter correspond with the sinuses of Valsalva (compare with *c* of Figs. 24 and 30).

PLATE XCIX.



Dr Pettigrew del. C. Berjeau lith. [illegible] imp.

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FIG. 10.—Another similar vein; the section being carried between instead of across or through the cusps, one of which is represented at *c*. At *e*, the lunular-shaped surface caused by the contact and flattening of the two cusps when the valve is closed is shown.

FIG. 11.—Wax cast of interior of left ventricle of deer. Shows spiral nature of the left ventricular cavity. This cast gives the precise shape assumed by the blood prior to its being forced into the aorta during the systole of the heart. *a*, *b*, *c*, Spiral ridge occurring between the two spiral grooves (*d*, *e*) occupied by the spiral musculi papillares. The spiral musculi papillares direct the blood on to the segments of the mitral valve in spiral waves, and so necessitate their spiral closure as seen at *d*, *e*, *f* of Figs. 26, 27 and 28, and *n*, *o* of Fig. 30. The blood is projected spirally from the left ventricle into the aorta like a rifle bullet.

FIGS. 12, 13, and 14.—Show the structure of the cusps or segments of the venous valves. Fig. 12, *a*, *b*, Longitudinal fibres; *c*, vertical fibres. Fig. 13, *d*, *e*, *f*, Radiating fibres. Fig. 14, *g*, *h*, Oblique intersecting fibres. The fibres support the segments in every direction on the principle that the stays and struts support the girder bridge.

FIGS. 15 and 16.—Show the structure of the cusps of the semilunar valve of the pulmonary artery in man. Fig. 15, one complete cusp (*b*, *c*) and portions of two others (*a*, *d*). At *b*, *c* the lunular portion of the cusp which comes into apposition with a neighbouring cusp when the valve is closed is shown (compare with *b*, *b′* of Fig. 21, and *a*, *b*, *c* of Fig. 22). Fig. 16, *a*, Fibrous tissue bifurcating (*b*, *c*); *d*, fibrous tissue bifurcating (*e*, *f*); *g*, mesial line of cusp. The cusp is folded upon itself at *g*, when the valve is closed as at *a*, *b*, *c*, *d*, *e*, *f* of Fig. 20.

FIG. 17.—Musculi papillares of left ventricles and segments of mitral valve of heart of calf. *a*, *b*, Bifurcated free ends of anterior musculus papillaris; *c*, *d*, bifurcated free ends of posterior musculus papillaris; *e*, *e′*, *f*, *f*, chordæ tendineæ splitting up to be inserted into the segments of the mitral valve; three on either side of the mesial line, three on either margin, and six in intermediate positions. The valve is thickest at the root (*g*) and central part, and thinnest at the apex (*h*) and margins. As the valve is supported and stayed in every direction it is enormously strong. The valves of the veins and arteries are similarly constructed, and can endure great pressure without being ruptured.

FIG. 18.—Musculi papillares and mitral valve of left ventricle of human heart in an inverted position. *a*, *b*, Anterior musculus papillaris giving off chordæ tendineæ (*e*) to anterior (*h*) and posterior (*i*) segments of mitral valve; *c*, posterior musculus papillaris giving off chordæ tendineæ (*f*, *i*); *g*, base of mitral valve. By twisting the anterior and posterior musculi papillares in different directions as indicated by the arrows, the margins of the segments (*h*, *i*) forming the mitral valve are brought together and the valve closed. It is opened by a reverse movement (compare with *d*, *e*, *f* of Figs. 26, 27, and 28, and *n*, *o* of Fig. 30).

FIG. 19.—Mitral valve of the heart of a sheep. *c*, *d*, Two sets of chordæ tendineæ which split up (*e*, *f*) and are inserted by brush-shaped expansions into the body of the valve; *g*, base of anterior segment of valve; *i*, apex of posterior segment; *h*, opening between the segments.

FIG. 20.—Section of the base of the ventricles of a sheep's heart, showing the mitral valve open and the semilunar valves of the aorta and pulmonary artery closed. The semilunar valves were closed by introducing liquid plaster of Paris into the aorta and pulmonary artery from above. The segments of the semilunar valves close in a distinctly spiral manner, as indicated by the curved arrows marked *a*, *b*, *c*, and *d*, *e*, *f*. *g*, Segment of mitral valve; *h*, *i*, anterior and posterior musculi papillares.

FIG. 21.—Human aortic semilunar valve closed by the aid of liquid plaster of Paris. When the plaster hardened, one of the segments of the valve was removed at *o*. *a*, *a′*, *b*, *b′*, Flat lunular surfaces seen on two of the three segments produced by the wedging and screwing of the third segment (which has been removed) against them; *d*, portion of wall of aorta. The amount of contact between the segments is increased by the degree of pressure, *a*, *a′* representing less pressure than *b*, *b′*.

FIG. 22.—Shows the nature and the amount of contact between the three cusps or segments forming the pulmonic and aortic semilunar valves. *a*, *b*, *c*, Margins of the three semilunar cusps bent and flattened against each other. The three cusps are spirally wedged into each other as represented by the arrows *d*, *e*, *f*. *g*, *h*, *i*, Points where the cusps are attached to the interior of the pulmonary artery and aorta.

FIG. 23.—Venous sinus from the auricle of the heart of a sturgeon. *a*, *b*, Sinus or valve; *d*, *e*, muscular arrangements for closing and opening it. The sinus or valve is partly tendinous and partly muscular.

FIG. 24.—Section of pulmonary artery, semilunar valve, and right ventricle of human heart. Shows how the pulmonary artery (*a*, *b*, *c*) diminishes in thickness behind the cusp (*j*) to form one of the sinuses of Valsalva. *f*, Interior of pulmonary artery; *g*, wall of right ventricle; *h*, portion of cusp of valve folded down.

FIG. 25.—Section of pulmonary artery and right ventricle of human heart between two cusps of the pulmonic semilunar valve. Shows the variation in thickness of the pulmonary artery (*a*, *b*), and how it bifurcates at its origin (*c*). *d*, *e*, Origin of pulmonary artery from fibrous ring; *i*, cusp of semilunar valve; *f*, thickened portion of aorta forming upper boundary of one of the sinuses of Valsalva; *g*, section of right ventricle; *h*, fibrous zone to which aorta is attached.

FIGS. 26, 27, and 28.—Base of the ventricles of the heart of a sheep; seen from above with the auricles removed. Show how the segments of the tricuspid and mitral valves screw and wedge into each other spirally when the valves are closed. The valves in the present case were closed artificially by injecting liquid plaster of Paris through the pulmonary artery and aorta into the ventricles. As the ventricles were filled the valves closed somewhat suddenly in the manner indicated, and so perfectly that not a drop of the liquid plaster of Paris escaped.

FIG. 26.—The segments of the tricuspid and mitral valves rolling up from beneath in a spiral manner (*vide* arrows *a*, *b*, *d*, *e*, *f*) preparatory to the closure of the valves. The valves when closing form funnel-shaped, spiral depressions. *g*, Orifice of aorta with semilunar valve open; *h*, orifice of pulmonary artery.

FIG. 27.—The segments of the tricuspid and mitral valves spirally wedged into each other (*vide* arrows *a*, *b*, *c*; *d*, *e*, *f*), and the valves closed prior to the segments being wedged home. In this case the segments present a flattened appearance above. *f*, Orifice of aorta with semilunar valve open; *g*, orifice of pulmonary artery.

FIG. 28.—The segments of the tricuspid and mitral valves spirally wedged home as they are at the end of the systole (*vide* arrows, *a, b, c; d, e, f*). In this case the segments bulge upwards into the auricles. *g*, Orifice of aorta with semilunar valve open; *h*, orifice of pulmonary artery.

FIG. 29.—Section of the right ventricle of the human heart. Shows the musculi papillares and tricuspid valve in position; the latter being open. *a*, Musculus papillaris giving off chordæ tendineæ to one segment of the tricuspid valve; *b, c*, two musculi papillares giving off chordæ tendineæ to a second segment (*g*); *d, e*, musculi papillares giving off chordæ tendineæ to the third segment (*f*). *h*, Arrow indicating the direction in which the segments are closed.

FIG. 30.—Plaster of Paris cast of the right and left ventricles, aorta, and pulmonary artery of the heart of a zebra, with the tricuspid and mitral valves closed. Shows how the right ventricular cavity (*j*) and cavity of pulmonary artery (*e*) curve round the left ventricular cavity (*i*) and cavity of aorta (*a*); further, how the blood takes the form of spiral wedges in the right and left ventricles; the blood closing the tricuspid and mitral valves and opening the pulmonic and aortic semilunar valves by spiral movements. *a*, Cavity of aorta; *b, c*, cavities of two of the three sinuses of Valsalva; *d*, funnel-shaped cavity leading from the left ventricular cavity to the cavity of the aorta—the wedge shape assumed by the blood being the best possible for opening the semilunar valves of the aorta (*a*); *e*, cavity of pulmonary artery; *f*, cavity of a sinus of Valsalva; *g*, portion of wall of aorta; *h*, portion of wall of pulmonary artery; *i*, cavity of the left ventricle; *j*, cavity of the right ventricle; *k*, portion of posterior musculus papillaris of left ventricle; *l*, portion of muscular fibres of left ventricle; *m*, portion of muscular fibres of right ventricle; *n, o*, segments of mitral valve spirally wedged into each other (*vide* arrows), the valve being closed; *p, q*, segments of tricuspid valves spirally wedged into each other (*vide* arrows), the valve being closed.

FIG. 31.—Left ventricle of human heart cut open to show the aortic semilunar valve, mitral valve, musculi papillares, &c., *in situ*. *a*, Aorta cut open and spread out; *b, c, d*, points where the cusps (*e, f, g*) of the semilunar valve are attached to the interior of the aorta; *h*, mitral valve; *i, j*, right and left musculi papillares giving off chordæ tendineæ to the segments of the mitral valve; *k*, arrow indicating the direction in which the mitral valve is closed; *l*, cavity of the left ventricle; *m*, portion of left auricle.

ARRANGEMENT OF THE MUSCULAR FIBRES IN THE HOLLOW VISCERA GENERALLY

The remarkable spiral arrangement of the muscular fibres in the ventricles of the heart is, curiously enough, repeated in other hollow viscera, namely, the bladder, œsophagus, stomach, uterus, &c. I have traced it with great care in the ventricles, bladder, stomach, œsophagus, and also, though not so exhaustively, in the uterus. Of these viscera I have made a large number of dissections, photographs, and drawings, those of the heart being preserved in the Anatomical Museum of the University of Edinburgh; those of the œsophagus, stomach, bladder, and uterus in the Hunterian Museum of the Royal College of Surgeons of England, London, where they are available for examination and reference.

The distribution of the muscular fibres in the bladder was fully described by me in a Memoir "On the Muscular Arrangements of the Bladder and Prostate, and the manner in which the Ureters and Urethra are closed," in the *Philosophical Transactions*, with three plates of photographs and drawings, in 1867.[1]

I give a synopsis of this Memoir and append two plates in illustration. The figures in the plates are selected from the original photographs and drawings with the object of enabling the reader to compare them with similar photographs and drawings of the left ventricle of the heart.

I also, with the same object in view, give a short original Memoir "On the Distribution of the Fibres in the Muscular Tunics of the Stomach of Man and other Mammalia," communicated to the Royal Society so far back as 1867. An abstract of this Memoir appeared in the *Proceedings of the Royal Society* on the 20th of June, 1867, but the Memoir itself, with its two plates of illustrations (twenty-four figures), is now published for the first time.

The arrangements of the muscular fibres in the heart, bladder, stomach, œsophagus, uterus, &c., have a far-reaching significance, especially in connection with muscular arrangements as a whole, with muscular contractions and dilatations, with the opening and closing of sphincters, the opening and closing of cavities with muscular walls, the flexion and extension of limbs and other parts connected with locomotion on land, on and in the water, and in the air. As I pointed out in 1872,[2] the hollow involuntary muscles are, in a sense, the progenitors and parents of the solid voluntary muscles, and nothing occurs in the latter which does not practically occur also in the former. The hollow muscles display independent centripetal and centrifugal movements; they act rhythmically; they act with or without nerves; they move on either side of a given line, the line representing their position of rest. The solid muscles do the same. The double power possessed by muscles, as displayed by their independent centripetal and centrifugal movements, is seen to great advantage in the stomach, where the sphincters co-ordinate the movements occurring in the walls of the viscus. The body of the stomach and its sphincters act in concert to given ends, and the same is true of other hollow viscera with sphincters, such as the bladder, uterus, and rectum. It is

[1] This Memoir, with others on the circulation, obtained for the Author in 1874 the Godard prize of the French Academy of Sciences.
[2] "On the Physiology of the Circulation in Plants, in the Lower Animals, and in Man" (*Edinburgh Medical Journal*, 1872–73).

also true of the extensor and flexor muscles of the extremities and other parts which take part in locomotion. A more or less extensive acquaintance with the structure and function of the involuntary muscles is absolutely necessary to a comprehension of the voluntary ones, and this fact, it appears to me, justifies a short digression on the muscular arrangements of the bladder and stomach.

§ 146. Arrangement of the Muscular Fibres in the Bladder and Prostate.

The human bladder, according to my dissections and photographs, consists of seven more or less perfect layers —three external, a fourth or central, and three internal, as in the left ventricle of the heart. The layers are composed of figure-of-8 loops, which produce an intricate network of fibres running practically in every direction. The bladder is consequently provided with stays, struts, and supports at all points, and is therefore a powerful organ, notwithstanding its thin distensible walls. The figure-of-8 loops made by the superficial or external layers extend between the urachus and the neck of the bladder, and are well seen on its anterior aspect. The deeper figure-of-8 fibres make larger loops round the urachus and neck of the viscus, and cross obliquely and symmetrically in the latter situation to form a well-marked and powerful sphincter. The central loops cross still more obliquely, and form what has been erroneously described as a circular layer. The fibres forming the loops of the internal layers are more delicate than those forming the loops of corresponding external layers. They are also fewer in number and more separated. These layers are thicker in some parts than in others. The arrangements described are seen in all parts of the viscus anteriorly, posteriorly, and laterally, and can be traced either from without or from within. They extend also to the prostate gland.

In some cases the arrangement at the urachus and neck of the bladder presents the appearance of a Maltese cross; four converging sets of loops crossing in four well-marked directions. The so-called circular fibres are well seen from the interior of the bladder or when the bladder is everted, and two sets of fibres can be seen entering into the formation of the sphincter at the neck of the viscus both externally and internally. The need for a powerful sphincter vesicæ becomes very apparent when it is remembered that normal urination occurs only every four or six hours. When it does occur the urine is extruded by a rhythmic forcible closing of the body of the bladder and a spontaneous rhythmic opening of its sphincter. The sphincter guards the narrow passage of the neck of the bladder, and closes it so accurately that not a drop of urine can escape. If the sphincter did not spontaneously open when the body of the bladder closed, no power possessed by the latter and its contained urine could possibly force the passage. It is here the double power possessed by muscles asserts itself. When the bladder closes by the centripetal movements of its fibres the sphincter opens by the centrifugal movements of its fibres. These movements are equally independent of each other. They form part of a co-ordinated, predetermined system, which has for its object the extrusion of the urine at stated intervals.

The bladder is a very complete receiving, retaining, and discharging organ. It is specially designed to open up, receive, contain, and discharge urine at longer or shorter periods. The receiving and containing functions are the opposite of the discharging function, from which it is quite certain that the urine does not act as an irritant and cause its own expulsion. The same cause could not possibly produce two diametrically opposite results. Similar remarks apply to the several compartments of the heart.

In both cases the object in view is to receive, retain, and transmit fluids, and this is accomplished by specially designed and originally endowed structures. An organ acts rhythmically when one part of it closes and another opens simultaneously, no regard being had to the frequency of the closing and opening movements. The rhythms in the human heart are generally about seventy per minute; in the bladder they occur, in a marked form, every four or six hours; in the stomach, provided five meals are taken daily, they are more frequent; in the uterus they vary according to the duration of pregnancy.

The rhythmic movements of the bladder connect it with similar movements in the heart and circulation generally.

PLATE C

This plate represents photographs by the Author of his dissections of the muscular arrangements of the human bladder and prostate. The dissections themselves are, as already indicated, preserved in the Hunterian Museum of the Royal College of Surgeons of England, London. The dissections were made according to the Author's hot-water process (*vide* Appendix I., "Anatomical Preparation Making, &c."). In some cases the bladders were moderately distended with hot water, in others with liquid plaster of Paris coloured with ultramarine blue. The blue plaster of Paris when it set or hardened afforded suitable support and a fine background for dissecting and

displaying the several layers of fibres. The deep colour of the plaster shone through the walls of the viscus, and threw even the most delicate fibres into bold relief. In certain cases the bladders, when dissected and subsequently hardened in spirit, were cut in two and the coloured plaster removed. They then became transparent and very beautiful objects.

FIG. 1.—Anterior view of young adult male bladder, showing longitudinal (*a*, *b*), slightly oblique (*c*, *d*, *e*, *f*), oblique (*g*, *h*, *i*, *j*), and very oblique (*k*, *l*, *m*, *n*) spiral figure-of-8 fibres, as seen in layers 1, 2, 3, and 4. *x*, Urachus.

FIG. 2.—Anterior view of adult female bladder. Shows slightly oblique (*c*, *d*, *e*, *f*), and oblique (*g*, *h*, *i*, *j*) spiral figure-of-8 fibres, with a few oval fibres, as observed in layers 2 and 3. *x*, Urachus.

FIG. 3.—Posterior view of young adult male bladder, showing longitudinal (*o*, *p*), slightly oblique (*q*, *t*), oblique (*u*, *v*, *w*, *x*), and very oblique (*y*, *y'*, *z*, *z'*) spiral figure-of-8 fibres, as seen in layers 1, 2, 3, and 4.

FIG. 4.—Posterior view of adult female bladder (transparent). Shows longitudinal (*o*, *p*), slightly oblique (*q*, *t*), and very oblique or circular fibres (*y*, *z*), as seen in layers 1, 2, and 4.

FIG. 5.—Left lateral view of young adult male bladder, showing longitudinal (*a*, *b*, *o*, *p*), slightly oblique (*c*, *d*), oblique (*h*, *i*), and very oblique (*k*, *l*, *m*, *n*) spiral figure-of-8 fibres, as seen in layers 1, 2, 3, and 4. *x*, Urachus.

FIG. 6.—Right lateral view of adult male bladder, showing longitudinal (*a*, *b*, *o*, *p*), slightly oblique (*p*, *q*), oblique (*g*, *h*), and very oblique (*k*) spiral fibres as seen in layers 1, 2, 3, and 4. *r*, Portion of ureter; *x*, urachus.

FIG. 7.—Anterior view of adult male bladder inverted, showing longitudinal (*a*, *b*), slightly oblique (*c*, *d*, *e*, *f*), oblique (*g*, *h*, *i*, *j*), and very oblique (*k*, *k'*) spiral figure-of-8 fibres, as seen in layers 7, 6, 5, and 4. The internal fibres are fewer in number and less developed than the external ones, but their directions, as a careful examination will show, are the same. *x*, Urachus inverted.

FIG. 8.—Anterior half of adult male bladder, seen from within (transparent). Shows longitudinal (*e*, *d*), oblique (*c*, *f*), and very oblique or circular fibres (*k*, *l*), forming the fourth or central layer; also the continuations of those fibres in a downward direction towards the cervix, where they are arranged in two sets (*m*, *m'*, *y*, *y'*), and are principally concerned in the formation of the sphincter vesicæ. *x*, Urachus, from within.

FIG. 9.—Posterior view of adult male bladder inverted. Shows longitudinal (*o*, *o'*, *p*, *p'*), and very oblique or circular fibres (*k*, *k'*, *l*, *l'*), as seen in layers 7 and 4.

FIG. 10.—Apex of adult male bladder—the bladder is placed on its posterior surface (transparent). Shows anterior (*a*), posterior (*o*), and right (*l*), and left (*k*) longitudinal fibres arranged in a crucial form, with the urachus as the central point, and in a minor degree the slightly oblique (*e*, *f*, *q*, *t*), oblique (*g*, *j*, *u*, *x*), and very oblique fibres. Compare with similar arrangement in Fig. 12, which represents the fundus and cervix of the same bladder.

FIG. 11.—Fundus and cervix of adult female bladder—the bladder is placed on its posterior surface, seen from within (transparent). Shows longitudinal (*b*), slightly oblique and oblique (*d*), and very oblique or circular (*e*) fibres, but principally the longitudinal and circular; also the continuity of the ureters (*r*, *r'*) with each other in the mesial line, and with the fibres of the uvula, &c.

FIG. 12.—Fundus and cervix of adult male bladder—the bladder is placed on its posterior surface (transparent). Shows anterior (*b*), posterior (*p*), and right (*n*) and left (*m*) longitudinal fibres arranged in a crucial form with the prostate (*z*) as a centre; and in a minor degree, the slightly oblique, oblique (*d*, *e*, *s*, *t*), and very oblique or circular (*v*, *v*). Compare with similar arrangements in Fig. 10, which represents the apex of the same bladder.

PLATE CI

This plate shows the arrangements of the muscular fibres in the human bladder and prostate as still further dissected by the Author; the distribution of the fibres in the bladder and prostate being illustrated by the aid of outline or skeletal drawings, which enable the reader to trace the figure-of-8 loops made by the fibres in the several layers, and especially in the central or so-called circular layer. It also shows that the sphincter of the bladder is formed from two sets of external and two sets of internal fibres, which cross more and more obliquely as the central layer is reached. The oblique and very oblique external and internal fibres are chiefly concerned in the formation of the sphincter.

It further shows photographs of the arrangements of the muscular fibres in the prostate and the first part of the urethral passage, and how that passage is round and pervious at its commencement, then crescent-shaped, then triangular and constricted, then obliterated, and then opened up circularly.

FIG. 1.—Represents in outline the various sets of fibres occurring on the anterior aspect of the bladder, as seen in layers 1, 2, 3, and 4. *a*, *b*, Longitudinal or vertical fibres forming layer 1; *c*, *e*, *d*, *f*, slightly oblique spiral figure-of-8 fibres embracing urachus (*x*) and urethra (*b*) posteriorly and forming layer 2; *g*, *h*, *i*, *j*, oblique spiral figure-of-8 fibres embracing upper third of bladder and lower portion of cervix posteriorly and forming layer 3; *k*, *l*, *m*, *n*, very oblique spiral figure-of-8 fibres embracing lower two-thirds of bladder and upper portion of cervix posteriorly and forming the fourth or central layer. The fibres of this layer enter principally into the formation of the sphincter, and, contrary to the received opinion, cross each other at very obtuse vertical angles.

PLATE C

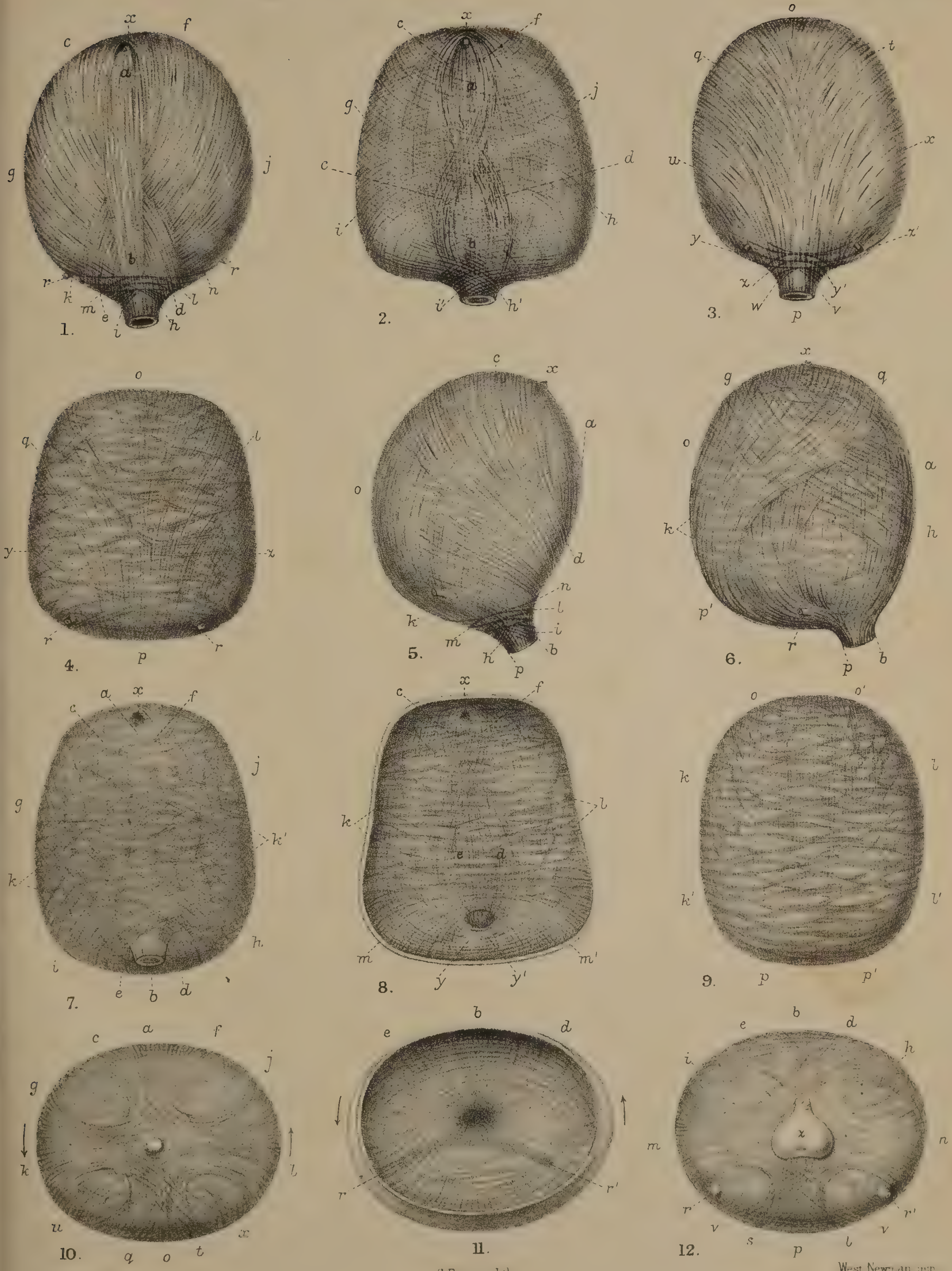

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Fig. 2.—Shows the same as Fig. 1, and, in addition, the manner in which the sphincter and fourth or circular layer is formed posteriorly. *g*, *j*, Terminal expansion or loop representing the spiral oblique fibres which spread out on the upper third of the bladder posteriorly, and assist in forming the central, transverse, or so-called circular layer in this direction. Its concomitant or companion loop embraces the cervix posteriorly, and assists in forming the posterior lip of the sphincter vesicæ; *k*, *n*, *k'*, *n'*, *k''*, *n''*, terminal expansions or loops representing very oblique spiral figure-of-8 fibres, forming the lower two-thirds of the fourth or central layer posteriorly. Their companion loops occur on the posterior aspect of the cervix, and are principally concerned in the formation of the posterior lip of the sphincter (*m*, *l*, *m'*, *l'*, *m''*, *l''*). The sphincter and the other portions of the fourth or central layer, as will be seen from this explanation, are not composed of circular fibres as is generally believed.

Fig. 3.—Represents the various sets of fibres occurring on the left lateral aspect of the bladder, as seen in layers 1, 2, 3, and 4. *a*, *b*, *o*, *p*, Anterior and posterior longitudinal fibres, as seen in layer 1; *c*, *c*, *e*, *s*, *t*, slightly oblique spiral figure-of-8 fibres embracing, loop-fashion, the urachus (*x*) and the urethra, as seen in layer 2; *g*, *h*, *h'*, *i*, *i'*, *j*, oblique spiral figure-of-8 fibres spreading out on upper third of right side of bladder and right side of sphincter, as seen in layer 3; *m*, *n*, *k*, *l*, very oblique spiral figure-of-8 fibres embracing lower two-thirds of right side of bladder and right side of sphincter.

Fig. 4.—Represents the various sets of fibres occurring on the posterior aspect of the bladder, as seen in layers 1, 2, 3, and 4. *o*, *p*, Longitudinal or vertical fibres forming layer 1; *q*, *r*, *s*, *t*, slightly oblique figure-of-8 fibres embracing urachus and urethra anteriorly, and forming layer 2; *u*, *v*, *w*, *x*, oblique spiral figure-of-8 fibres embracing upper third of bladder and lower portion of cervix anteriorly, and forming layer 3; *y*, *y'*, *z*, *z'*, very oblique spiral figure-of-8 fibres embracing lower two-thirds of bladder and upper portion of cervix anteriorly, and forming the fourth or central layer.

Fig. 5.—Shows the same as Fig. 4, and, in addition, the manner in which the sphincter and fourth or central layer is formed anteriorly. *u*, *x*, Terminal expansion or loop representing the spiral oblique fibres which spread out on the upper third of the bladder anteriorly, and assist in forming the central, transverse, or circular layer in this direction. Its companion loop embraces the cervix anteriorly, and assists in forming the anterior lip of the sphincter. *y*, *z*, *y'*, *z'*, *y''*, *z''*, Terminal expansions or loops representing the very oblique spiral figure-of-8 fibres, forming the lower two-thirds of the fourth or central layer anteriorly. Their companion loops occur on the anterior aspect of the cervix, and are principally concerned in the formation of the sphincter, *z*, *y*, *z*, *y*, *z*, *y*.

Fig. 6.—Represents the manner in which the sphincter and the fourth or central layer is formed on the left side of the bladder. *n*, *k*, *n*, *k*, *n*, *k*, Terminal expansions or loops formed by the very oblique spiral figure-of-8 fibres which spread out on the left side of the bladder and form the fourth or circular layer in this situation. Their companion loops occur on the left side of the cervix, and contribute to the formation of the sphincter in this situation (*m*, *m*, *m*; *l*, *l*, *l*).

Fig. 7.—Transverse section of prostate and urethra at cervix (male). *m*, Very oblique so-called circular fibres of urethra forming the sphincter. Compare with *m*, *m'*, *m''*; *l*, *l'*, *l''*, of Fig. 2, and *z*, *z*, *z*; *y*, *y*, *y* of Fig. 5.

Fig. 8.—Transverse section of female urethra near the cervix. *m*, Very oblique so-called circular fibres forming the sphincter vesicæ; *z*, upper surface of urethra; *y*, openings for vessels.

Fig. 9.—Transverse section of prostate and urethra quarter of an inch from the cervix (male). *m*, Very oblique so-called circular fibres of the prostatic portion of the urethra. Compare with *m*, *m'*, *m''*; *l*, *l'*, *ll''*, of Fig. 2 and *z*, *z*, *z*; *y*, *y*, *y* of Fig. 5. *x*, Oval band of fibres surrounding the ducts of the vesiculæ seminales.

Fig. 10.—Transverse section of prostate and urethra half an inch from the cervix (male). *m*, Very oblique or circular fibres of the urethra blending with similar fibres belonging to the prostate (*o*); *n*, fibres belonging to the urethra and partly to the prostate radiating in the substance of the gland from the verumontanum (*r*) as a central point; *x*, circular band of fibres embracing the ducts of the vesiculæ seminales.

Fig. 11.—Transverse section of prostate and prostatic portion of male urethra half an inch from the base of prostate. *m*, Very oblique so-called circular fibres of the urethra blending with corresponding fibres belonging to the prostate (*o*); *r*, verumontanum with fibres radiating from it which belong partly to the prostate and partly to the urethra.

Fig. 12.—Another and similar section nearer apex of prostate. *m*, Very oblique or so-called circular fibres of the urethra; *o*, corresponding fibres of the prostate; *g*, *g'*, under surface of prostate.

Fig. 13.—Transverse section of prostate and prostatic portion of urethra at base of prostate (male). *m*, Very oblique so-called circular fibres of urethra where sphincter is most fully developed; *o*, corresponding fibres of the prostate. Those fibres are distinct from each other at this point, and are separated by a considerable interval. *x*, Oval band of fibres surrounding ducts of vesiculæ seminales.

Fig. 14.—Transverse section of prostate and prostatic portion of urethra rather more than a quarter of an inch from the base of prostate (male). *m*, Very oblique so-called circular fibres of urethra; *o*, very oblique so-called circular fibres of prostate curving into the verumontanum (*r*), where they blend with the circular and other fibres of the urethra; the relation existing between the urethra and prostate in this section is of the most intimate description.

Fig. 15.—Vertical section of fundus of bladder and male prostate in the vicinity of the urethra. Shows continuity of fibres and intimate connection between the two. *a*, Longitudinal fibres from anterior wall of bladder proceeding to dorsum of prostate (*b*) and dorsal surface of urethra (*w*); *o*, longitudinal fibres from posterior wall of bladder proceeding to ventral surface of prostate (*h*) and ventral surface of urethra (*w*).

Fig. 16.—Vertical section of the parts at the neck of the bladder in the adult female. *a*, Longitudinal fibres from anterior wall of bladder bifurcating; some proceeding to dorsum of urethra (*b*), others in a downward direction (*l*); *o*, longitudinal fibres from posterior wall of bladder proceeding to the ventral surface of urethra (*p*), and in an upward direction (*l*); *m*, very oblique so-called circular fibres surrounding urethra and forming the sphincter vesicæ. Compare with *m*, *m'*, *m''*; *l*, *l'*, *l''* of Fig. 2, and *z*, *z*, *z*; *y*, *y*, *y* of Fig. 5.

Fig. 17.—Horizontal section of cervix and prostate in adult male. *a*, Longitudinal fibres from right lateral wall of bladder passing across to left lateral aspect of prostate (*d*); *e*, longitudinal fibres from left lateral wall of bladder passing to right lateral aspect of prostate (*b*); *m*, some of the terminal loops of the posterior figure-of-8 fibres; *o*, oblique passage of urethra; *p*, seminal passage.

Fig. 18.—Horizontal section of cervix of bladder and prostate near centre of gland (male). *a*, Longitudinal fibres from right

lateral wall of bladder proceeding to right side of prostate (*b*) and across to left side of bladder (*c*); *c*, longitudinal fibres from left lateral wall of bladder proceeding to left side of prostate (*d*) and across to right side of bladder (*a*); *n*, peculiar stellate arrangement of fibres, indicating contractile power: urethral passage obliterated.

Fig. 19.—Vertical section of fundus of bladder and prostate (male). Shows intimate relation existing between bladder and prostate, and how some of the longitudinal fibres from the anterior wall (*a*) proceed to the dorsal surface of the gland (*i*), some passing through it (*f*) and reaching its ventral surface (*x*, *x′*). It also shows how some of the longitudinal fibres from the posterior wall (*h*) pass on to the ventral surface (*c*), while others curve in an upward direction to reach the dorsal surface (*i*, *y*). The fibres cross obliquely at *w* and assist in forming the sphincter vesicæ.

Fig. 20.—Horizontal section of cervix and prostate in adult male. *a*, Longitudinal fibres from right side bifurcating, some passing to right side of prostate (*b*), others passing in a lateral direction to left side of bladder (*d*); *c*, longitudinal fibres from left side of bladder proceeding to left side of prostate (*d*), and to right side of bladder (*a*). These fibres represent certain of the terminal loops. *s*, Oblique passage of urethra.

Figs. 21, 22, 23, 24, 25, 26, 27, 28, and 29.—Accurate outline sketches of transverse sections of male prostate and urethra, showing the precise shape and degree of obliquity in the urethral canal at different points, and the part which the verumontanum plays in the closure of it. *a*, Urethral canal at base of prostate, circular, and quite open; *b*, urethral canal a little further forward, floor (*j*) slightly elevated; *c*, urethral canal somewhat triangular in shape; the verumontanum (*k*) beginning to project from the floor; *d* and *e*, urethral canal more decidedly triangular, the verumontanum (*l* and *m*) projecting to such an extent as almost to occlude it; *f* and *g*, urethral canal entirely closed by the projection of the verumontanum (*n*, *o*), which acts at this point as a mechanical wedge; *h*, *i*, *p*, *q*, urethral canal circular and again becoming patent.

Fig. 30.—Vertical section of neck of bladder, urethra, and prostate (greatly enlarged). Shows how the urethra is to be regarded as the proper continuation of the bladder in an antero-posterior direction, and how the prostate is formed by the splitting up of the four outer tunics of the bladder. 1′. Longitudinal fibres of first layer splitting up at cervix—a certain number (*a*, *a′*) investing the prostate (*q*) on its dorsal aspect; some proceeding to the dorsal surface of the urethra (*b*, *b′*), and some (*c*) to the under or ventral surface of the prostate (*q′*). 2′. Slightly oblique spiral fibres of second layer splitting up (*d*), and passing into the substance of the prostate (*d′*, *d′*, *d″*) and into the second layer of the urethra (*e*, *e′*). 3′. Oblique spiral fibres of third layer splitting up (*f*); some passing through the prostate (*f′*, *f″*), others proceeding to the third layer of the urethra. 4′. *d′*, Cut ends of a portion of the very oblique spiral fibres of fourth layer, forming the so-called circular fibres of the prostate (*g*, *g′*), the remainder occupying the centre of the walls of the urethra. 1, 2, and 3. The three external layers of the bladder and urethra. 4. The central so-called circular layer. A portion of each of these layers, as has been explained, go to form the prostate. 5, 6, and 7. The three internal layers of the bladder and urethra. These layers are peculiar to the urethra, and are quite distinct from the three external layers forming the prostate and the outer half of the urethra, unless in the region of the verumontanum, where they are more or less blended with them.

Fig. 31.—Shows the conformation of the fundus and the bilateral nature of the sphincter in the inverted bladder, the prostatic portion of urethra being moved. In this figure the anterior and posterior sets of fibres only are shown. *a*, *b*, Anterior and posterior longitudinal submucous fibres; *l*, *l*, *l*; *l′*, *l′*, *l′*, terminal expansions or loops of the very oblique spiral fibres forming the fourth layer at the fundus posteriorly, and especially concerned in the formation of the anterior lip of the sphincter (*l′*); *y*, *y*, *y*; *y′*, *y′*, *y″*, terminal expansions or loops of the very oblique spiral fibres forming the fourth layer at the fundus anteriorly, and especially concerned in the formation of the posterior lip of the sphincter (*m′*); *r* and *s*, spiral oblique fibres from the right and left ureters (*z*, *v*), which give off filaments to assist in the formation of the sphincter (*l′*, *y′*).

§ 147. The Distribution of the Fibres in the Muscular Coats of the Stomach of Man and other Mammalia.[1]

The arrangement of the muscular fibres in the stomachs of mammals is difficult to determine because of the great tenuity of the layers (particularly the superficial ones) forming the parietes of the viscus.

In man, to which the following description more particularly applies, they are best seen in the young adult

[1] My researches on the muscular arrangements of the mammalian stomach date back to the years 1865 and 1866. In these years I made an elaborate series of dissections, and examined in succession the stomachs of the several domestic animals, also of the whale, porpoise, bear, puma, sloth, coebus monkey, howling monkey, orang-outang, chimpanzee, and particularly man. Some of these were examined both in the fœtal and adult states. The dissections were made at, and the majority of them are preserved in, the Hunterian Museum of the Royal College of Surgeons of England, London.

During the period in which I was engaged on this work at the Museum I had frequent visits from the late Dr. Allen Thomson, Professor of Anatomy in the University of Glasgow, who induced me to give him, as one of the editors of Quain's "Anatomy," advance descriptions and drawings of them for the seventh edition of that popular book, which seventh edition was published in 1867.

In that year (1867) I communicated a Memoir, bearing the above title, to the Royal Society with two plates containing twenty-four figures.

The Memoir was duly read to the Royal Society, and an abstract of it published in the Proceedings of the Society under date June 20, 1867 (volume xvi.); the Memoir itself being, I understood, assigned a place in the *Philosophical Transactions*, as was the case with other Memoirs presented by me previously.

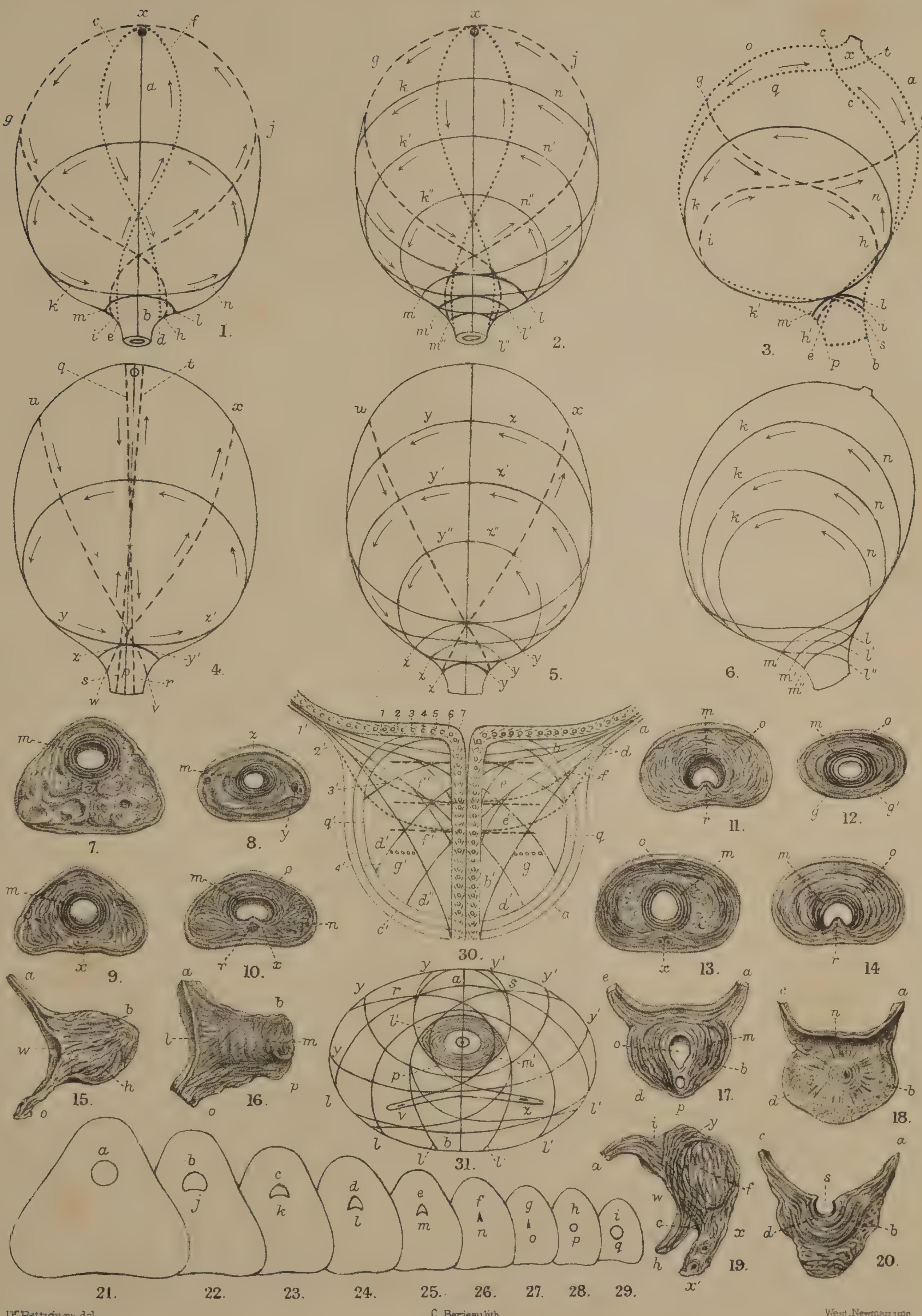
The Memoir was strangely and unaccountably suppressed, and the only reason I can give for its suppression is, that Professor Allen Thomson was one of the referees for its publication, and may have thought that the advance preliminary descriptions and drawings with which I furnished him for Quain's "Anatomy," and which he duly incorporated in the seventh edition mixed up with descriptions of his own, my drawings being labelled "After Pettigrew and from nature," would suffice.

Curiously enough, while Professor Allen Thomson's indebtedness was duly acknowledged in the seventh edition of Quain, the indebtedness is not referred to in later editions (tenth edition, 1896), my work and drawings being exclusively attributed to Dr. Thomson, and his name alone appearing in connection with them.

The Memoir has had a strange history. As a matter of fact it has been locked up in the Archives of the Royal Society since 1867 until the present year of grace (1908), a period of over forty years. The Memoir is now published for the first time, *in its entirety, with its original illustrations.* The advanced views it contains regarding the arrangement of the muscular fibres of the stomach, the discovery of a new cardiac or œsophageal sphincter, the unravelling of the muscular fibres forming the pyloric sphincter, together with much original matter concerning the complex co-ordinated movements of the stomach and its sphincters, and the physiology of the stomach generally, ought to have saved it from the obscurity to which it was unfortunately relegated.

From the foregoing it will be evident that the submitting of Memoirs intended for publication by the Royal Society to irresponsible referees from whom there is no appeal is, or may be, fraught with great hardship to authors.

PLATE CI.



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stomach when quite fresh and before the specimen has been blanched by coming in contact with water or alcohol. A strong light is requisite for the examination. The distribution resembles that found in the heart [1] and bladder,[2] that is, it consists of a series of longitudinal, slightly oblique, and very oblique fibres, which intersect each other at given angles; the slightly oblique intersecting at acute angles; the oblique and very oblique, at obtuse ones. The oblique fibres are spiral in their nature and form, or tend to form figure-of-8 loops. These loops are directed towards the greater and lesser curvatures of the stomach, but are also traceable on the great cul-de-sac or fundus, and on the lesser cul-de-sac or antrum pylori. The figure-of-8 arrangement is not so perfect as in the bladder, although in the deeper or more central fibres it can readily be made out. As a result of the figure-of-8 looped distribution of the fibres, the root of the œsophagus, and the pylorus, or narrow end of the stomach, are invested with oblique and very oblique fibres. These fibres pursue opposite directions, and are arranged in two sets, so that they surround the entrance into, and exit from, the stomach after the manner of sphincters.

The crossing and lopping of the fibres extend also to the body of the viscus, and show that the so-called circular layer is in reality composed of very oblique spiral fibres intersecting at very obtuse angles.

The stomach is bilaterally symmetrical; the fibres being arranged in such a manner that they co-ordinate each other: the longitudinal fibres intersecting the very oblique so-called circular fibres at nearly right angles; the slightly oblique and oblique spiral fibres proceeding from right to left and from left to right respectively, so that they mutually cross and interlace. This arrangement secures great strength and admits of very precise and varied movements.

The fibres radiate and converge, as in the bladder and heart, to adapt themselves to the twisted, curved cone formed by the stomach.

The fibres are arranged in different sets, and may be divided into *external* and *internal* strata.

The external fibres are less fully developed than the internal, and the fibres, as a whole, are most strongly pronounced in the direction of the pylorus. Towards the cardiac end they are in some instances, as in old, flaccid stomachs, extremely delicate; although in others—in young, muscular stomachs, for example—they are well marked and easily traced.

The external and internal fibres are united to each other by a mutual interchange of fibrous filaments, and the fibres of the several strata interweave to a slight extent, so that the term layer must be used in a restricted sense.

The layers are indicated by the prevailing direction of the fibres, and are seven in number; three external, three internal, with an intermediate or central layer between.

The fibres having the same direction are, in some instances, strongly developed at one part of their course and feebly at another. They even become gradually attenuated until they are no longer visible. The superficial and sub-mucous layers are, from this circumstance, more or less imperfect in parts.

The muscular coats of the stomach are thickest towards the pylorus [3] and root of the œsophagus, where the aggregations of oblique fibres constituting the sphincters in those situations occur; then along the lesser curvature on either side of the mesial line; then along the greater curvature. They are thinnest on the anterior and posterior surfaces, and towards the cardiac end of the viscus.

The gradual diminution in the thickness of the coats of the stomach referred to is occasioned by the fibres of one layer or stratum radiating and becoming thinner and more delicate, while those of another and opposite layer converge and become thicker and stronger; it usually happening that the stronger fibres supplement the weaker ones, so that the parietes of the stomach, although not of uniform thickness, are not suddenly strong and weak in parts, but graduated. The only sudden thickening occurs in the shape of two ridges which run along the lesser curvature, and which, in the human stomach, are about an inch apart. They are very distinct in the stomach of the cat, and can also be detected in the stomach of the monkey. The mucous rugæ or ridges which project into the interior of the stomach, and pursue a more or less longitudinal direction, are due, in some measure, to the presence of longitudinal muscular fibres. These fibres represent the internal longitudinal fibres.

In the stomach of some of the lower animals, and in the fœtal condition of the viscus, the arrangement of the fibres is very simple, consisting as it does of a series of longitudinal and circular fibres intersecting each other at right angles. This arrangement is well seen in the stomach of the fœtal sheep, and also in the stomach of the porpoise. In the latter, the fibres on the dorsal aspect pursue a slightly oblique spiral direction, but they are confined to this region, and are not mixed up with the longitudinal and circular fibres which form two well-marked layers. The arrangement of the fibres into longitudinal and what are practically circular fibres is the more natural if the stomach is to be regarded, as it must be, as an expansion or dilatation of the alimentary canal. The twofold

[1] "On the Arrangement of the Muscular Fibres in the Ventricles of the Vertebrate Heart, with Physiological Remarks," by the Author. (*Philosophical Transactions*, Part III. 1864, page 445.)

[2] "On the Muscular Arrangements of the Bladder and Prostate, and the Manner in which the Ureters and Urethra are closed," by the Author. (*Philosophical Transactions*, Part I. 1867.)

[3] In the stomach of the bear, the walls of the antrum are fully a quarter of an inch thick.

distribution of the fibres, so evident in the intestine, is, however, materially modified whilst the stomach is being formed; the slightest dilatation or swelling of the alimentary canal producing a certain degree of obliquity both in the longitudinal and circular fibres. In order, therefore, to admit of the requisite degree of expansion and contraction in the greater and lesser culs-de-sac, the fibres of necessity radiate and converge to accommodate themselves to the peculiar form of the several parts of the viscus. It is, consequently, along the greater and lesser curvatures that the fibres exhibit a more decidedly longitudinal and circular character.

On the anterior and posterior surfaces, the great mass of the fibres, particularly in the higher Mammalia (man and monkey), pursue an oblique spiral direction; the oblique fibres crossing, as has been stated, with great regularity at wider and wider vertical angles as the central layer or stratum is reached.

The longitudinal fibres are greatly in excess in the stomach of the bear. Here they form a thick, continuous layer which obscures, to a considerable extent, the oblique and so-called circular fibres. The oblique and circular fibres are found in considerable numbers in the stomach of the cat and howling monkey, so that the usual division of the fibres into longitudinal, oblique, and circular may be regarded as expressing the arrangement in a general way. These terms, however, are at present employed very vaguely, and appear to have been transferred from descriptions of the intestine and rudimentary stomach, and applied to the perfected organ, without the latter having been examined with that attention it deserves. It will, moreover, be readily understood that what is true of the arrangement of the fibres in the fœtal stomach, and in the paunch of the ruminants, does not necessarily hold good of the organ in the omnivora, where a single stomach has substantially to perform the duties of four stomachs. This involves a more complicated arrangement, and necessitates the higher degree of differentiation in the fibres to which I have directed attention in the foregoing remarks. The dissections, on which my descriptions are based, are preserved for the most part in the Hunterian Museum of the Royal College of Surgeons of England, London, and include the stomachs of several of the domestic animals, and also those of the porpoise, whale, bear, cœbus monkey, orang-outang, chimpanzee, gorilla, and man.

It has been explained that considerable advantage is always gained by examining the stomach immediately after its removal from the body, and before it becomes blanched by coming in contact with fluids. Failing this, the best method is to distend it with water and hold it against the light as a semi-transparent object; or to tinge the water injected into the stomach with some deep colour, and view it as an opaque object; the colour shining through the parietes and throwing the fibres into relief. I have also found it very useful to stain the viscus with carmine; this expedient enabling me to detect the direction of some delicate fibres not as yet described, and to determine with accuracy the courses of others at present imperfectly known. In order to bring out the delicate fibres referred to more strongly, I have, in some instances, caused the whole viscus to contract artificially by first distending it gently with air and then forcibly immersing it in very hot water, or by simply injecting it with very hot water. Under these circumstances, the stomach contracts and is reduced to about one-third its natural dimensions, and those fibres which could scarcely be perceived by the naked eye because of their paucity and extreme minuteness, are made to stand boldly out. If the specimen is to be preserved, the best plan is to distend it moderately with plaster of Paris coloured with ultramarine blue, or to stain the parietes with carmine, and fill it with uncoloured plaster of Paris. In either case the direction and position of the fibres is rendered more evident.

Longitudinal External Fibres.—These fibres, as their name indicates, run in the direction of the long axis of the viscus. They are strongly marked in the fœtal stomach of the sheep, in the paunch of the ruminants, in the corresponding receptacle in the porpoise and whale, in the bear, and likewise in the cat. They are less manifest in the stomach of the dog, orang-outang, and man.

If a fresh human stomach be distended with water or plaster of Paris, or made to contract with very hot or boiling water as recommended, the external longitudinal fibres are readily seen. They present a more or less reticulated appearance, are most strongly marked at the root of the œsophagus, and naturally arrange themselves into two sets; one set proceeding along the lesser curvature in the direction of the pylorus, where they gradually lose themselves;[1] the other proceeding along the great cul-de-sac where, in thin, flaccid stomachs, they gradually disappear. In well-developed muscular stomachs, the last-named fibres are continued along the greater curvature in the direction of the pylorus.

Running parallel with the two principal sets of longitudinal fibres which confine themselves to the lesser and greater curvatures of the stomach, are a series of minute longitudinal fibres which may be traced on all parts of the anterior and posterior surfaces of the viscus. They are feebly developed in the direction of the lesser curvature, more fully towards the greater curvature, and are most numerous and strongly marked towards the pylorus. At the great fundus they are so fine that they require to be sought for. They arise from an imperfectly formed raphe (well seen in the cat), which divides the great fundus into two halves. Some of the fibres are independent of the

[1] The corresponding fibres in the bear occur as a strong fibrous band.

raphe in question, and sweep round the great curvature in a lateral direction, as shown in the stomachs of the cat, bear, and dog, so that they cross the proper longitudinal fibres of the great curvature (that is, the fibres from the œsophagus) nearly at right angles. The anterior and posterior longitudinal fibres are, as has been stated, strongly pronounced in the bear. In the human stomach they form a continuous but delicate layer.

Slightly Oblique External Fibres.—These are arranged in two sets. They pursue a slightly oblique spiral direction; the one set proceeding from right to left downwards, the other from left to right downwards. They are seen to advantage on the anterior surface and fundus of the cat's stomach (compare with similar fibres in the stomach of the bear, and dog; see Plate cii., Figs. 11 and 13). They plainly intersect and cross each other. In the monkey, and in man, they are exceedingly delicate, and require to be sought for by the aid of a strong light, before the serous membrane investing the stomach is removed, and before the stomach is rendered pale by coming in contact with water, or alcohol. They are most distinctly pronounced in the vicinity of the œsophagus, where they present a radiating appearance, and along the lesser and greater curvatures. They gradually disappear between the curvatures anteriorly and posteriorly, and so form a thin imperfect layer. On the œsophagus they run between the longitudinal fibres on the anterior and posterior surfaces; the longitudinal fibres confining themselves more especially to the right and left aspects of this portion of the alimentary canal. They are well seen in the œsophagus of the horse and bear. In some cases the longitudinal and slightly oblique œsophageal fibres are blended together. The fibres described as longitudinal and slightly oblique can also be traced in the stomach of the orang-outang.

Oblique External Fibres.—Beneath the longitudinal and slightly oblique fibres described, and radiating alternately from the greater fundus towards the lesser fundus, and *vice versâ*, are two sets of strong oblique fibres. These fibres occasion by their crossing a thickening of the anterior and posterior walls of the stomach. The anterior thickening is increased by corresponding interior fibres to be described presently.

It is particularly well seen in the stomach of the cat, and occurs where the longitudinal and slightly oblique fibres are weakest or absent; the fibres of the several tunics, as has been explained, supplementing each other.

§ 148. Œsophageal or Cardiac Sphincter not hitherto described.

The two sets of fibres under consideration form spiral loops which are arranged along the lesser curvature and great fundus like so many pot-hooks. Their arrangement is very symmetrical: the one set proceeding from left to right; the other from right to left. They embrace the root of the œsophagus and, with similar deeper fibres to be described subsequently, form a well-marked œsophageal or cardiac sphincter. They gradually lose themselves in the direction of the greater curvature, and so form an imperfect layer.

These fibres, with the very oblique fibres to be next described, clearly indicate the bilateral nature of the stomach. They extend in an upward direction along the œsophagus. In the œsophagus of the horse and bear similar fibres can be distinctly seen to cross each other anteriorly and posteriorly.

Very Oblique so-called Circular Fibres forming Central Layer.—Still deeper than either of the fibres spoken of, and crossing each other at very obtuse angles, are two sets of very oblique spiral fibres. These fibres are strongly pronounced in the stomach of the monkey, gorilla, orang-outang, and chimpanzee; and likewise in the human stomach. Because of the manner in which they radiate they are more oblique towards the cardiac and pyloric extremities of the viscus than in the more central portions. They cross at obtuse angles on the œsophagus, and on the anterior and posterior surfaces of the stomach generally, and form spiral, figure-of-8 loops; the terminal portions of which are directed towards the anterior and posterior surfaces respectively. The terminal portions of the loops in question form by their blending what is commonly known as the circular layer; this layer being in reality composed of very oblique spiral fibres, intersecting at very obtuse angles. The two sets of fibres forming the so-called circular layer are everywhere strongly marked, and form a layer of nearly uniform thickness.

§ 149. The Pyloric Sphincter—its Ultimate Structure.

Towards the pylorus, and particularly in the vicinity of the pyloric sphincter or valve, the oblique fibres become more and more aggregated together, and form by the crossing of their terminal portions a well-marked and bilaterally symmetrical pyloric valve, similar in all respects to that occurring at the neck of the bladder. (See m, m', m''; l, l', l'' of Fig. 2, and z, z', z''; y, y', y'' of Fig. 5 of Plate ci.)

The crossing of the fibres anteriorly and posteriorly, and the conformation of the pyloric sphincter, can readily be made out in the human stomach, and are best seen when the stomach is everted, divested of its mucous lining, and examined from within. The subjoined figure represents, according to my dissections (1865–66), the two sets

of fibres forming the pyloric sphincter crossing anteriorly and posteriorly; one half of the sphincter being represented by the continuous line of the figure, the other by the interrupted or dotted line.

The continuous and dotted lines of the figure (179), when superposed, represent the pyloric sphincter in its entirety.

The pyloric sphincter of the human stomach forms what is virtually a nearly circular muscular ring. This ring, however, is composed of two sets of very oblique spiral fibres. It projects on the internal surface of the organ to the extent of nearly a quarter of an inch on the greater curvature, and rather more than an eighth of an inch on the lesser. The nearly circular muscular projection or ring referred to is best seen when the stomach is distended with plaster of Paris hardened in alcohol and then cut open in the mesial line. It is conical in shape, the base being directed towards the outer surface of the stomach.

The nearly circular, conical-shaped muscular projection or ring constituting the pyloric sphincter is occasioned by the thickening of the fibres in its immediate vicinity, and by the coats of the stomach having folded and doubled upon themselves during development, in such a manner as to enable the outer surfaces subsequently to unite. This is proved by the presence of a white fibrous marking in the centre of the ring-like projection which indicates the line of junction, and by the fact that the smaller or pyloric end of the stomach naturally throws itself into folds which only require to adhere to form rudimentary sphincters. It is a curious circumstance, that the folds under consideration are continued into the smaller intestine (duodenum) and assist in forming the valvulæ conniventes. That muscular fibres enter into the composition of the valvulæ conniventes may be ascertained by distending and hardening the intestine with alcohol, and then making transverse sections of the valvulæ and the gut. This point can also be determined by removing a small portion of the duodenum, and causing the walls of the gut to flap together in an outward direction transversely, so as to place them and one of the valvulæ on nearly the same plane. If the portion of duodenum so prepared be soaked in a solution of carmine, placed between two microscopic slides, and pressed firmly together, the oblique and circular fibres of the intestine, if a low power is employed, are seen to project between the folds of the mucous lining of the gut, in the form of a small cone which imparts a certain degree of support to the valvulæ, otherwise somewhat flaccid.

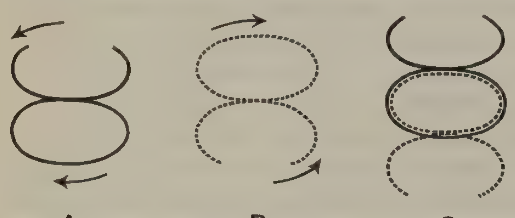


Fig. 179.

The valvulæ conniventes are spiral in their nature, and consist of two sets; the free extremities of the one set fitting into the closed extremities or loops formed by the other set.

If this view be adopted, the pyloric valve or sphincter of the stomach, which is the largest and most perfect of the folds into which the intestine is thrown, may be regarded as the centre of a system, whose function is to retard the passage of the food and increase the surface exposed to its influence.

In the stomach of the dog, the pyloric valve or sphincter has quite the appearance presented by two contiguous typical valvulæ conniventes.

Oblique Internal Fibres.—Beneath the central so-called circular layer which separates the external from the internal layers are two sets of oblique spiral fibres largely developed in man, in the monkeys, and particularly in the cat. They form loops which invest the œsophagus in two directions; the one set inclining towards the pylorus or small end of the stomach, the other towards the large end or great cul-de-sac. These fibres are most strongly marked in the vicinity of the œsophagus, where they converge to form two thick collars or cravats, which invest the root of the œsophagus symmetrically on its right and left aspects. These fibrous cravats, in conjunction with similar external cravats already referred to, form a well-marked œsophageal or cardiac sphincter, hitherto overlooked.

This sphincter acts powerfully, and completely closes the cardiac end of the stomach during the process of digestion.

While the two sets of fibres under consideration converge in the direction of the œsophagus, they radiate towards the greater curvature; one set extending itself in graceful curves on the anterior and posterior surfaces of the stomach, in the direction of the great cul-de-sac; the second set extending itself in like manner in the direction of the antrum pylori or small cul-de-sac. Towards the lesser curvature one of the sets forms a very distinct thickening of the walls of the stomach, which may be observed from the outside even before any of the fibres are removed. The thickening alluded to is very well marked in the stomachs of some of the lower animals—the cat in particular.

In the direction of the greater curvature the fibres of both sets become thinner and finer; the fibres modifying their direction towards the great cul-de-sac to blend with the very oblique fibres constituting the central, so-called circular layer; others blending with similar fibres in the direction of the pylorus. The two sets of oblique fibres,

as will be perceived, form an imperfect layer; the layer being deficient along the lesser curvature on either side of the mesial line, and also towards the cardiac and pyloric extremities of the viscus.

Slightly Oblique and Longitudinal Internal Fibres.—To the inside of the foregoing layer, and immediately beneath the mucous membrane of the stomach, a few straggling fibres, having in some instances a slightly oblique, and in others a nearly longitudinal direction, may be detected. The longitudinal fibres are best seen on the interior of the œsophagus, and the slightly oblique on the anterior and posterior surfaces of the interior of the stomach. In the latter situations they correspond to the rugæ. They can only be seen when the stomach is everted, hardened in alcohol, and the mucous lining removed. They can scarcely be said to form distinct layers.

If I have rightly interpreted the facts with which my numerous dissections have supplied me, it would appear that while the distribution of the fibres in stomachs of the same age and belonging to the same animals is invariable, the number of the fibres, as well as the complexity of their arrangement, is increased in the higher mammalia; in other words, a gradual increase in the number and in the obliquity of the fibres may be observed as we proceed from the fœtal to the adult stomach, and from the stomach of the herbivora, through the carnivora, and on to the omnivora; the most highly differentiated stomachs being those of man and the monkey.

It will further appear that the fibres of the stomach have neither origin nor insertion, and that in this, as well as in their general arrangement, they notably resemble the fibres of the heart, bladder, and uterus.

Not the least interesting feature in the distribution is the symmetry which everywhere prevails; the fibres being so disposed that they act in concert in certain areas and upon the stomach as a whole; the external and internal longitudinal fibres, assisted by the slightly oblique external and internal spiral fibres, shortening by their contraction the stomach in its long diameter; the oblique and very oblique spiral fibres which form the central or what has been termed the circular layer, diminishing its antero-posterior or short diameter. The stomach, like other hollow viscera, has the power of opening and closing, this double power being traceable to the centripetal action of the muscular fibres composing it.

The œsophageal and pyloric extremities of the stomach are similarly constituted, and both are provided with bilaterally symmetrical sphincters.

This is a matter of very considerable importance in the economy of the stomach; the viscus by this arrangement being endowed with power not only to receive and discharge the food at stated intervals, but also to retain it in a closed sac during the primary stages of digestion. As a matter of fact, the cardiac and pyloric sphincters, and the general arrangement of the muscular fibres of the stomach as a whole, enable the viscus to receive and retain food, to roll about and knead the food, and to discharge it at intervals into the duodenum as required. The stomach practically deals with food as an intelligent agent would.

MOVEMENTS OF THE HUMAN STOMACH AND ITS SPHINCTERS

A consideration of the arrangement of the muscular fibres of the human stomach and its sphincters affords the clue to the movements of the several parts of the viscus during digestion.

These movements are at once complex and peculiar.

The stomach causes the food to gyrate along its greater and lesser curvatures. It also exerts a cross or antero-posterior action which churns or kneads the food. The food is also impelled obliquely. As a matter of fact, the food is made to travel longitudinally, transversely, and obliquely; an arrangement which ensures that every portion of it shall be brought into contact with every part of the mucous lining of the stomach and the gastric juice exuded by the gastric glands, and so reduced to the pasty or semi-fluid condition known as chyme.

The movements in question could be seen in the case of Alexis St. Martin, the Canadian boatman, who when fowling had his abdomen and part of the anterior wall of his stomach opened by a gun-shot wound.

While the movements of the body of the stomach are remarkable, those of its sphincters are peculiarly so.

The stomach, as I have pointed out, is supplied with an œsophageal or cardiac sphincter as well as a pyloric sphincter, and the extraordinary part of the arrangement consists in the fact that the two sphincters have their movements definitely co-ordinated to given ends and act in concert. Acting in concert does not in this case necessarily mean acting at the same time or in the same direction. On the contrary, the movements of the sphincters at times are diametrically opposed to each other; the cardiac sphincter being open when the pyloric one is closed, and *vice versâ*. It happens occasionally that at one time both sphincters are open, while at another time they are both closed. This extraordinary diversity of movement in the cardiac and pyloric sphincters is necessary to the stomach receiving, retaining, and discharging food in the process of alimentation.

When food is taken the cardiac sphincter is open and the pyloric one closed. When food is being digested both

sphincters are closed. When a certain portion of the food has been reduced to chyme and has to be extruded into the small intestine, the pyloric sphincter is opened—the cardiac one remaining closed. When no food is in the stomach, both sphincters are open or partially open.

The very remarkable movements of the cardiac and pyloric sphincters are vital in their nature; that is, they are not caused by the food acting as an irritant and producing the simultaneous opening or closing of the two sphincters at one time, or the opening of the one sphincter and the closing of the other at another time. The same food, however broken up and chemically changed, could not possibly produce these diverse results. It could not consistently be the occasion of synchronously closing and keeping closed one part of the stomach and opening and keeping open another part. The food which is always present in the stomach during digestion could not produce the intermittent or rhythmic movements which the stomach and its sphincters display. A continuous stimulus could not occasion an interrupted or irregular movement. The rhythmic movements inhere in the parts moving, and are the result of original endowment and design. They are multiple, compound, co-ordinated movements, which cannot be explained by mere irritability of the parts or by extraneous stimulation.

If the food were accredited with opening the cardiac sphincter, it could not be accredited with closing the pyloric sphincter, and the converse. These are diametrically opposite movements. Neither could it be accredited with the closing of both sphincters. The movements of the sphincters must be regarded as fundamental, co-ordinated, designed movements.

Further, the movements of each sphincter are spontaneous and independent: in other words, each sphincter opens and closes of its own accord—the opening movement being as much a vital movement as the closing one. This follows because there is no power in the stomach when it contracts to force the passages of the sphincters. In the case of the pyloric sphincter especially, the aperture or passage being exceedingly small, no very powerful muscular contraction on the part of the sphincter is required to close and make it absolutely impervious. The pyloric sphincter when closed cannot be opened by any pressure exerted by the body of the stomach or the food contained in the stomach.

The pyloric sphincter opens when the stomach closes, and *vice versâ*, precisely as in the several compartments of the heart. What is true of the pyloric sphincter is also true, within limits, of the cardiac sphincter.

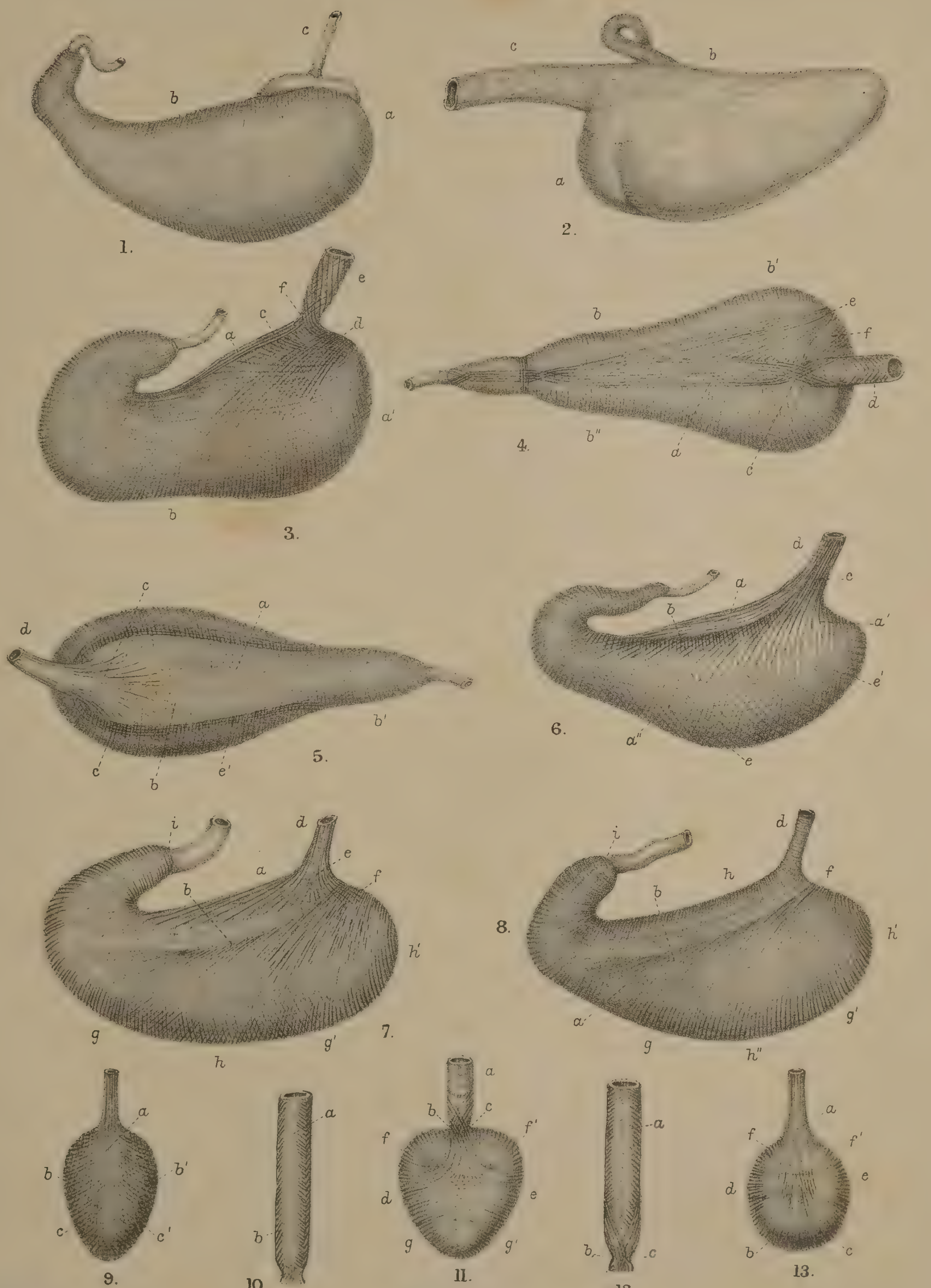
The cardiac sphincter is situated between the root of the œsophagus and the cardiac or great end of the stomach. The œsophagus, however, is part of the alimentary system, and every part of that system is endowed with the double power of opening and closing; the part which opens the one instant, closing the next, and conversely. Viewed in connection with the remarkable properties of the œsophagus, the double power now claimed for the cardiac and pyloric sphincters will occasion no surprise. As a matter of fact the muscular arrangements met with in the stomach and its sphincters exist in a simpler form in the œsophagus itself. While the bolus of food in the act of swallowing is the occasion or opportunity for the rhythmical, vermiform movements of the œsophagus, it does not cause the movements. On the contrary, the œsophagus seizes the food presented to it and transmits it to the stomach by alternately opening before and closing behind it. If, as is generally believed, the food acts as an irritant and stimulant, and causes the movements of the œsophagus, the bolus of food in its passage to the stomach would cause the œsophagus to contract in front of the food (the point of contact of the advancing bolus) and not behind it. The closure in front would, it need scarcely be stated, prevent the transmission of the food.

We have only to consider the matter from a common-sense point of view to be assured of this. That the movements of the œsophagus are inherent and vital, as well as spontaneous, is proved by this. If the food while being swallowed gets beyond a certain point it is, *nolens volens*, conveyed into the stomach. In vomiting, the movements of the œsophagus are reversed. In ruminating animals the food is hastily swallowed and not masticated. It is subsequently regurgitated or vomited, by a reversed action of the œsophagus, carefully chewed, and swallowed a second time. The swallowing and regurgitation or vomiting are normal acts in the ruminants—the œsophagus acting alternately in two directions, namely, from above downwards and from below upwards. Here the inherent and voluntary movements of the œsophagus are both evoked. As illustrating the voluntary aspect of the question an acrobat can swallow water or food when standing on his head. In rare cases, man is endowed with the power of ruminating—that is, he can convey, by a voluntary reversal of the movements of his œsophagus, part of the contents of his stomach into his mouth, as happens in animals which chew the cud. Regurgitation, in these cases, is another name for vomiting; the peculiarity being that the individual can control and regulate the vomiting process.

The alimentary canal, as a whole, is expressly formed to seize, transmit, retain, and discharge the food and drink required to nourish and sustain the body, and it is erroneous to suppose that the food causes the movements whereby it is made to enter and leave the body. The presence of food in the several parts of the alimentary canal no more causes the movements of these parts than the sight of food causes us to eat when we are not hungry.

I do not here enter upon a consideration of the nerve supply of the œsophagus and stomach, as the nerves in

PLATE CII.



D^r Pettigrew del. C. Berjeau lith. West, Newman imp.

FROM DISSECTIONS AND DRAWINGS, BY J. BELL PETTIGREW, M.D. EDIN.

the case of involuntary muscular arrangements do not of themselves cause the movements. All that can be said under this head is that the nerves take part in and, within limits, regulate the movements. The function of the nerves is largely that of correlating muscular movements. The nerves also regulate the supply of blood and the nourishment of the tissues to which the vessels are distributed.

Illustrative examples of the dual loss of power in the muscles and nerves are to be found in paralysis of the bladder and lower bowel. In paralysis of the bladder, the rhythmic co-ordinated movements of the viscus and its sphincter are destroyed, and, as a consequence, the bladder fills and overflows, the urine dribbling away. Incontinence of urine, even in the absence of paralysis, is largely a nervous disorder. In paralysis of the lower bowel, the rhythmic co-ordinated movements of the rectum and its sphincters are destroyed and the fæces escape involuntarily. A good example of the effect of nerves in regulating nutrition and supplying tone is furnished by paralysis of a limb where the muscles and other parts atrophy and diminish in volume and power. The muscular degeneration and nutritive processes, as was shown by Dr. John Reid, can be corrected, up to a point, by stimulating and exercising the muscles periodically by the application of galvanism, massage, &c.

That muscles and nerves in the higher animals each take part in producing associated movements admits of direct proof. If a motor nerve be divided the muscles to which it is distributed are paralysed.

The œsophagus, stomach, and alimentary canal belong to one of several vital systems in which are included the heart, kidneys, bladder, uterus, organs of reproduction, lungs, &c. They are all necessary to life, as we know it, and, as I have already explained on several occasions, living things, whether plants or animals, are superior to their surroundings and can select and reject whatever matter is required for their well-being, whether solids, fluids, or gases. The solids, fluids, and gases do not invade plants and animals; plants and animals, on the contrary, attack, appropriate, and assimilate the solids, fluids, and gases, which they use and abuse in the sense that they extract from them whatever is essential and useful in building up and maintaining their own bodies in a state of health, while they reject and throw off whatever is inimical or what ultimately becomes detritus or waste products.

PLATE CII

The figures of this plate, taken from my original dissections and drawings, show the arrangement of the muscular fibres in the stomach of the fœtal sheep, porpoise, bear, cat, dog, howling monkey, chimpanzee, &c.

Fig. 1.—Stomach of a fœtal sheep. *a*, Longitudinal muscular fibres; *b*, transverse muscular fibres. These fibres, usually called circular, are composed of the terminal loops of very oblique fibres. The latter form a continuous layer.

Fig. 2.—Stomach of a porpoise. *a*, Longitudinal muscular fibres; transverse muscular fibres. These form two well-developed, continuous layers. *c*, Œsophagus.

Fig. 3.—Anterior view of the stomach of a bear. *a*, *a*, Longitudinal muscular fibres forming a continuous powerful layer; *b*, transverse muscular fibres also forming a strong continuous layer; *c*, oblique, looped, radiating fibres with the connections of the loops directed towards the œsophagus (*e*); *d*, similar but opposite fibres. These two sets of looped fibres grasp and constrict the lower portion of the œsophagus, and so take part in the formation of the œsophageal or cardiac sphincter seen at *f*. *e*, Two sets of oblique spiral fibres crossing and forming part of the œsophagus.

Fig. 4.—The lesser curvature of a bear's stomach, partly dissected, seen from above. *a*, Longitudinal muscular fibres, some of which radiate and interdigitate with fibres spreading from the cardiac end of stomach (*e*); *b*, transverse muscular fibres forming a strongly marked layer; *c*, longitudinal muscular fibres crossing at the root of the œsophagus, and taking part in the formation of the œsophageal or cardiac sphincter (compare with *b*, *c*, of Fig. 11); *d*, two sets of very oblique spiral muscular fibres crossing and forming part of the œsophagus (compare with *a* of Figs. 11 and 12). The arrangement of the muscular fibres in the œsophagus resembles that of the stomach itself. *e*, Muscular fibres which radiate from the cardiac end of the stomach and reach the mesial line longitudinal muscular fibres at various angles with which they interdigitate; *f*, muscular fibres which radiate from the cardiac end of the stomach (compare with *g*′, *g*′, of Fig. 11).

Fig. 5.—The lesser curvature of the cat's stomach, seen from above. *a*, Longitudinal muscular fibres forming a continuous layer; *b*, transverse muscular fibres forming a continuous layer; *c*, muscular fibres radiating from the root of the œsophagus. These fibres are strongly marked in the human stomach. *d*, Straight fibres forming the outer layer of the œsophagus; *e*, *e*, one of two characteristic ridges or thickenings found on the lesser curvature and composed of straight, oblique, and very oblique fibres. These ridges limit or bound the lesser curvature—they separate it from the anterior and posterior surfaces of the stomach.

Fig. 6.—Anterior view of cat's stomach. *a*, Longitudinal fibres on the lesser curvature of the stomach; *a*′, longitudinal fibres on the anterior surface; *b*, two sets of oblique fibres crossing and forming a partial layer along the lesser curvature of the stomach. Part of these fibres (*c*) proceed from the root of the œsophagus (*d*). *e*, *e*, Similar oblique fibres crossing and forming a partial layer along the greater curvature of the stomach.

Fig. 7.—Stomach of howling monkey, seen anteriorly. *a*, Longitudinal radiating fibres in the lesser curvature of the stomach; *a*′, similar fibres on the anterior and posterior surfaces of the stomach; *b*, muscular ridge or thickening analogous to that seen at *e*, *e* of Fig. 5 and *b* of Fig. 6 in the stomach of the cat. The ridge is caused by the muscular fibres marked *f* in figure radiating and curving in the direction of the greater curvature of the stomach (*g*, *g*′). These fibres form a nearly perfect layer. *c*, Muscular fibres radiating from the root of the œsophagus (*d*) on the cardiac end of the stomach; *e*, transverse fibres composed of terminal layers of very oblique fibres. They form a strong continuous layer. *h*, *h*, Site of pyloric valve.

FIG. 8.—Anterior view of stomach of chimpanzee. *a*, Longitudinal muscular fibres forming an imperfect thin layer; *b*, muscular fibres corresponding in direction with the fibres marked *b′* in Fig. 7, and the ridge *e*, *e* in Fig. 5; *f*, muscular fibres radiating in oblique curves towards the greater curvature of the stomach (*g*, *g′*). They form a nearly perfect layer on the anterior and posterior surfaces of the stomach, especially in the direction of the greater curvature. *h*, Transverse muscular fibres forming a thick layer, especially on the lesser curvature of the stomach.

FIG. 9.—Cardiac end of stomach of zebra. *a*, Vertical straight muscular fibres; *b*, transverse muscular fibres; *c*, *c*, oblique curved muscular fibres radiating from vertical muscular fibres.

FIG. 10.—Œsophagus of bear. Shows two sets of oblique muscular fibres.

FIG. 11.—Cardiac end of stomach of bear with œsophagus. Shows cruciform radiating arrangement of the muscular fibres. *a*, Two sets of very oblique muscular fibres, forming part of the œsophagus; *b*, *c*, two sets of slightly oblique muscular fibres crossing at the root of the œsophagus, and arranging themselves at nearly right angles in the centre of the cardiac end of the stomach. These fibres assist in forming the œsophageal or cardiac sphincter. They also take part in the crucial arrangement to which reference has been made. *d*, *e*, Muscular fibres forming part of the cross; *f*, *f*, symmetrical muscular fibres springing from mesial line of cardiac end of stomach, and curving downwards and forwards to form the half of the longitudinal fibres on the anterior and posterior surfaces of the stomach; *g*, *g′*, radiating muscular fibres which assist in forming the upper portion of the cardiac end of the stomach, further seen at *f* of Fig. 4.

FIG. 12.—Œsophagus of the stomach of the bear. *b*, *c*, Slightly oblique spiral muscular fibres crossing at the lower end of the œsophagus, and assisting in the formation of the œsophageal or cardiac sphincter; seen also at *f* of Fig. 3, *c* of Fig. 4, and *b*, *c* of Fig. 11.

FIG. 13.—Œsophagus and cardiac end of dog's stomach. *a*, Straight vertical muscular fibres at root of œsophagus radiating at greater curvature of stomach (*b*, *c*); *d*, *e*, crucial muscular fibres, radiating to form the longitudinal fibres on middle portion of the anterior and posterior surfaces of the stomach (compare *b*, *c*, *d*, *e* of this figure with *f*, *f′*, *d*, *e* of Fig. 11); *g*, *g′*, radiating muscular fibres which form the longitudinal fibres on the upper portion of anterior and posterior surfaces.

PLATE CIII

The figures of this plate are from my original dissections and drawings, and display the arrangement of the muscular fibres in the human stomach.

FIG. 1.—Shows the longitudinal muscular fibres on the œsophagus (*a*) and on the greater (*b*) and lesser (*c*) curvatures of the stomach. These fibres extend to the anterior (*d*, *d′*) and posterior surfaces of the viscus, and form its superficial or first layer. Certain of the longitudinal fibres of the œsophagus (*a*) radiate and taper off on the anterior and posterior surfaces of the stomach, and also along the lesser curvature (*c*). The radiating fibres occurring in the lesser curvature are well seen at Fig. 8, *e*, *e*. The longitudinal fibres of the superficial or first layer are greatly developed in the stomachs of the fœtal sheep (Plate cii., Fig. 1), porpoise (Plate cii., Fig. 2), and bear (Plate cii., Fig. 3). Beneath the first layer, and confined more especially to the greater (*f*, *g*) and lesser (*c*) curvatures of the stomach, are two sets of delicate spiral oblique fibres which cross each other at acute angles. The fibres on the lesser curvature proceed from the pyloric end of the stomach and cross the fibres which radiate from the root of the œsophagus at *e*. Those on the greater curvature (*f*, *g*) cross at *b*. The fibres under consideration form parts of the second and third layers depicted in Fig. 2, and are here described from the fact that they are removed with the serous membrane of the stomach in exposing the deeper layers by dissection. *h*, Groove indicating the situation of the pyloric valve or sphincter of the stomach. The pyloric sphincter is seen at Figs. 10 and 11 *c*.

FIG. 2.—*i*, *j*, Two sets of strong, oblique, radiating fibres which cross each other and form figure-of-8 loops alternately directed to right and left. They constitute, in conjunction with similar deeper fibres (Fig. 5, p. 9) to be subsequently described, the œsophageal sphincter. Another view of the sphincter is given at Fig. 8, *i*, *j*. The fibres marked *j* spread along the lesser curvature of the stomach, where they form a characteristic thickening or ridge strongly marked in the cat (Plate cii., Figs. 5 and 6, *w*, *w*). The fibres marked *i* and *j*, when they contract, pinch the root of the œsophagus and form a powerful sphincter. The fibres in question constitute the second and third layers of the stomach. These layers in the human stomach are incomplete. They are more fully developed in the stomachs of the howling monkey and chimpanzee (Plate cii., Figs. 7 and 8, *w*, *w*). *k*, The so-called circular muscular fibres of the œsophagus. These are composed of two sets of loops seen at the root of the human œsophagus and also in the œsophagus of the bear (Plate cii., Figs. 4, 11, and 12). In the cat the fibres on the interior of the oesophagus are arranged in two sets of transverse loops which mutually embrace each other, as the valvulæ conniventes do in the duodenum (Fig. *g*, *b*, *c*). In the dog the pyloric valve or sphincter consists of two symmetrical halves inclined towards each other; each half being composed of a crescentric, projecting loop as in the valvulæ conniventes. *l*, *l*, Portion of the fourth or central and so-called circular layer. The fibres of this layer are not really circular. On the contrary, they consist of spiral figure-of-8 loops which cross each other very obliquely; the loops, which appear as a uniform layer on the anterior surface of the stomach, being composed of fibres which cross on the posterior surface and the converse.

FIG. 3.—*l*, *l′*, Anterior view of the fourth or central layer, composed of the terminal loops of fibres which cross very obliquely figure-of-8 fashion on the posterior aspect of the stomach. This layer is well developed, and envelops the whole stomach. It is well seen in the stomach of the fœtal sheep, porpoise, and bear (Plate cii., Figs. 1, 2, and 3), and forms the boundary between the external and internal layers. *m*, Longitudinal fibres at the root of the œsophagus blending with the fibres of the fourth layer.

FIG. 4.—*m*, *n*, Anterior view of the spiral very oblique figure-of-8 crossing fibres. The terminal loops of these fibres form the fourth or central layer on the posterior aspect of the stomach. The fibres of this layer cross spirally also in the œsophagus (*e*). The fourth or central layer is compound in the sense that it is composed of very oblique spiral crossing and looped fibres on both the anterior and posterior surfaces of the stomach. It is the most perfect and powerful of all the layers.

FIG. 5.—The muscular fibres in this figure are for the most part deeper repetitions of the fibres seen in Figs. 1 and 2; thus the fibres marked *r* correspond with the longitudinal fibres *a* of Fig. 1; the longitudinal fibres *c*, *s* corresponding with the longitudinal fibres *c*, *d*, *d′* of Fig. 1; and the spiral oblique looped fibres *p*, *q* corresponding with the spiral oblique looped fibres *i*, *j* of Fig. 2. The fibres in this figure form more or less continuous longitudinal and oblique layers, and make up for the deficiencies in similar

PLATE CIII.

D^r Pettigrew del. C.Bejeau lith. West Newman imp.

FROM DISSECTIONS AND DRAWINGS BY J. BELL PETTIGREW M.D., EDIN

layers seen in Figs. 1 and 2. They play an important part in the formation of the œsophageal sphincter, and form layers five and six of the human stomach. The longitudinal fibres *c*, *s* form the seventh or most internal layer. *r*, Internal longitudinal fibres of œsophagus.

FIG. 6.—Section of human stomach showing root of œsophagus (*a*); half of pyloric valve (*h*); and mucous membrane of rugæ (*t*) of interior of stomach. Delicate longitudinal fibres can be seen through the mucous lining with which some of them blend.

FIG. 7.—Dissection of the œsophagus of the horse, showing the straight, slightly oblique, oblique, and transverse spiral fibres. *a*, External layer composed of straight fibres; *e*, internal layer composed of straight fibres. These form layers one and seven of the œsophagus; *b*, slightly oblique spiral external and internal fibres crossing and forming layers two and six; *c*, very oblique spiral external and internal fibres crossing and forming layers three and five; *d*, the so-called circular fibres composed of figure-of-8 loops which form the fourth or central layer. The different layers of the œsophagus of the human stomach are given at Figs. 1, 2, 3, 4, and 5.

FIG. 8.—The œsophagus and lesser curvature of the human stomach, seen from above. *a*, Œsophagus showing straight fibres; straight fibres also extend between *a* and *c* (see Fig. 5, *c*); *e*, *e*, fibres which radiate from the root of the œsophagus along the mesial line of the lesser curvature of the stomach. These radiating fibres also extend to the anterior and posterior surfaces of the stomach (see Fig. 1, *e*). *d*, Longitudinal fibres found on anterior and posterior surfaces of stomach (see Fig. 1, *d*, *d′*, and Fig. 5, *s*); *l*, terminal figure-of-8 loops forming the so-called circular fibres (see Fig. 3, *l*, *l*); *m*, faint looped curved fibres with the loops directed towards the pyloric end of the stomach (see Fig. 1, *e*); *i*, *j*, strong bands of spiral figure-of-8 looped fibres which invest the root of the œsophagus and furnish a powerful œsophageal sphincter. These bands are seen at Fig. 2, *i*, *j*, and Fig. 5, *p*, *q*.

FIG. 9.—Portion of human duodenum showing how the valvulæ conniventes interdigitate and do not form continuous circles. In this respect they resemble the so-called circular fibres of the œsophagus. As explained, the latter form a series of loops well seen in the œsophagus of the cat when the œsophagus is everted. These loops in the œsophagus of the cat and the valvulæ conniventes in man bear a striking resemblance to each other. Similar loops form the œsophageal and pyloric sphincters of the stomach itself. *a*, External surface of duodenum; *b*, *c*, valvulæ conniventes occurring in the internal or mucous surface; these, as stated, dovetail into each other.

FIG. 10.—Pyloric end of human stomach, showing pyloric valve or sphincter and portion of duodenum. *a*, Pyloric end of stomach; *b*, portion of duodenum; *c*, pyloric valve. This valve is not composed of circular muscular fibres, as is generally believed, but of spiral, very oblique, looped fibres which cross each other symmetrically, precisely as the fibres marked *i*, *j*, Fig. 2; *p*, *q* in Fig. 5; and *i*, *j* of Fig. 8. These latter form the œsophageal sphincter. The pyloric and œsophageal sphincters are formed on the same plan. The sphincter of the bladder is formed in precisely the same manner. See sphincter vesicæ in Plate ci., Figs. 1 to 6 inclusive. The pyloric sphincter is a very powerful one with a comparatively small aperture, and the body of the stomach has no power to open it forcibly. As a matter of fact it opens spontaneously when the body of the stomach contracts. Similar remarks are to be made of the sphincter and bodies of the bladder, rectum, uterus, &c.

FIG. 11.—Section of the pyloric end of the human stomach, sphincter, and duodenum. *a*, Pyloric end of stomach; *b*, first part of duodenum; *c*, constriction formed by the pyloric valve, seen also at *h* of Figs. 1, 2, and 6.

§ 150. Analogy between the Muscular Arrangements and Movements of the Hollow Viscera (Heart, Stomach, Bladder, Uterus, &c.), and those of the Trunk and Extremities of Vertebrates.

The distribution and direction of the muscles and muscular fibres of the trunk and extremities of vertebrates accord in a wonderful manner with those described in the ventricles of the heart of the mammal; the arrangement of the muscular fibres in the ventricles closely corresponding with that in the stomach, bladder, and uterus. This is a remarkable circumstance, and merits the attention of all interested in homologies. If, for example, the thoracic portion of the human trunk be examined, we find longitudinal, slightly oblique, oblique, and transverse muscles, arranged symmetrically and in pairs as in the ventricles. Thus, in the region of the thorax anteriorly we have the symmetrical muscular masses constituting the pectorals and deltoids, the fibres of which are arranged vertically, transversely, and at various degrees of obliquity. The fibres of these muscles, if extended, would intersect as in the ventricles. Beneath the pectorals and deltoids we find the external and internal intercostal muscles running obliquely and crossing each other as in the letter X; while the serrati muscles run transversely and nearly at right angles to both (Fig. 180).

In the region of the abdomen this arrangement is repeated. Thus, we have the recti muscles running in the direction of the length of the trunk; the transversales abdominis running across the trunk or at right angles to the recti; and the external and internal oblique muscles running diagonally between the recti and transversales and crossing each other (Figs. 180, 181, and 182).

Proceeding to the posterior and lateral aspect of the thoracic region of the trunk a similar arrangement presents itself. Thus, in the trapezii we have the homologues of the pectorals, with fibres running in a more or less longitudinal direction, obliquely and transversely, and which would intersect if extended. Beneath the trapezii we have the rhomboidei and splenii crossing obliquely as in the letter X. The longitudinal muscles of this region are represented by the levatores anguli scapulæ, the accessorii, the longissimi dorsi, spinales dorsi, and semi-spinales dorsi. The slightly oblique muscles are represented by the levatores costarum, the multifidi spinæ, the transversales colli, &c.; and the transverse muscles by the serrati (p. 286, Plate lxxviii.; p. 287, Figs. 50, 51; p. 288, Figs. 52, 53, 54).

This subject is treated very fully further on.

Proceeding to the loins and the region corresponding to the abdomen behind, the arrangement again repeats

itself. In the quadrati lumborum, erectores spinales, and sacri lumbales, we have longitudinal muscles; in the multifidi spinæ, slightly oblique muscles; and in the latissimi dorsi, oblique muscles. If, therefore, I eliminate the element of bone from the thorax and abdomen, there will remain a muscular mass with fibres running longitudinally, slightly obliquely, obliquely, and transversely; the longitudinal muscles intersecting the transverse muscles at right angles, the slightly oblique muscles intersecting each other at acute angles, and the oblique ones at obtuse angles, symmetrically as in the ventricles of the heart. We have consequently in the thorax and abdomen two hollow muscular masses closely allied to the auricles and ventricles of the heart; the one opening when the other closes, and *vice versâ*. This follows because the bones of the trunk, while they transmit, do not originate movement. Nor does the resemblance stop here. Between the thorax and abdomen there is a movable muscular partition—the diaphragm, which descends when the thorax opens and the abdomen closes. A precisely similar function is performed by the mitral and tricuspid valves of the heart, two tendinous structures situated between the auricles and ventricles. The thoracic and abdominal movements are correlated for the reception and discharge of air, food, urine, fæces, &c., in the same way that the movements of the auricles and ventricles are correlated for the reception and discharge of blood. The thorax may be said to pump and suck air; the heart blood. In the diaphragm, the muscular fibres are arranged at right angles, slightly obliquely, and obliquely, as in the ventricles, thorax, and abdomen. This curious muscle may consequently be compared to half a heart, half a stomach, or half a bladder. The diaphragm, like the hollow viscera, chest, abdomen, &c., acts by alternately shortening and elongating its fibres. When it elongates its fibres, it ascends and diminishes the thorax; when it shortens them, it descends and enlarges the thorax. This arrangement provides for the diaphragm oscillating on either side of a given line. The diaphragm ascends when the ribs descend, and *vice versâ*. The ascent of the diaphragm and the descent of the ribs diminish the capacity of the thorax, and increase that of the abdomen; the descent of the diaphragm and the ascent of the ribs increase the capacity of the thorax, and diminish that of the abdomen. When the thorax expands and the abdomen closes, a wave of motion passes from the symphysis pubis in the direction of the ensiform cartilage; a reverse wave passing from above downwards when the abdomen expands and the thorax closes. The lines representing these waves of motion cross each other figure-of-8 fashion in forced expiration and inspiration. The muscular arrangements in the hollow viscera and diaphragm and in the human trunk and extremities, here described, are more fully explained and illustrated by the aid of finished drawings towards the end of the work.

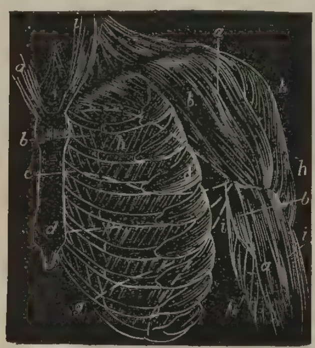


FIG. 180.

FIG. 181.

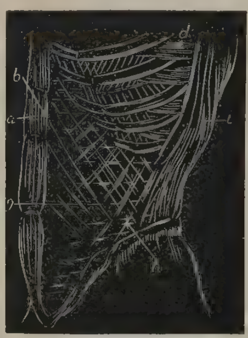


FIG. 182.

FIGS. 180, 181, and 182. Show how the muscles of the human chest, arm, fore-arm, and abdomen run in vertical, slightly oblique, oblique, and transverse directions, as in the heart (left ventricle), and cross, or tend to cross, each other (the Author, 1872).

The arrangements in question appear in a simple form in the body of the fish. They are seen to advantage in the body of the manatee, a sea mammal in which the extremities are rudimentary.[1] They reappear in the extremities when these are sufficiently developed. Thus, in the human arm the biceps represents the longitudinal fibres, the supinator longus and flexor carpi radialis the slightly oblique fibres, the pronator radii teres and flexor sublimis digitorum the oblique fibres, and the pronator quadratus the transverse fibres (Fig. 181).

Stranger than all, the bones of the extremities are twisted upon themselves and correspond to the mould or cast obtained from the cavity of the left ventricle of the heart, which shows that the bones mould and adapt themselves to the muscles, and not the converse. The muscles of the extremities are arranged around their spiral bones as the muscles of the ventricles are arranged around their spiral cavities. These points are illustrated at Figs. 183–185.

As the soft tissues precede the hard in the scale of being, I am disposed to tabulate the muscles thus: First, the heart and hollow muscles, which act independently of bone; second, the muscles of the trunk, which act in conjunction with bone; third, the muscles of the extremities, also connected with bone. I place the hollow muscles first, because they are found before any trunk proper exists; the trunk muscles second, because the thorax and abdomen precede the limbs; and the muscles of the extremities third, because the limbs are differentiations which are only found in the higher animals.

As bones appear comparatively late in the scale of being, I regard the hollow involuntary muscles as typical

[1] *Vide* a fine memoir on this rare animal by Dr. James Murie. (*Trans. Zool. Soc.*, vol. viii., plate 21.)

of the solid voluntary muscles, both as to the direction of their fibres and their mode of action. The term solid is here applied to the voluntary muscles from the fact that they invest bones and have no cavities in their interior; the involuntary muscles, on the other hand, surround cavities and have no connection with bone. The muscular fibres of the ventricles of the heart, as explained, are arranged longitudinally, transversely, and at various degrees of obliquity, symmetrically, and with something like mathematical accuracy. The fibres are not to be regarded as in any sense antagonistic. Thus the longitudinal fibres do not pull against the transverse, nor the various oblique fibres against each other. On the contrary, the fibres act together and consentaneously. When the ventricle is to be closed, all the fibres shorten and broaden by centripetal movements; when it is to be opened, they all elongate and narrow by centrifugal movements. These movements are definitely co-ordinated. The muscles do not exhaust themselves in a suicidal warfare. The function of the ventricles is to draw in and eject blood, and this can only be done economically in the manner explained. In like manner analogy and a variety of circumstances, to be alluded to presently, convince me that the muscular masses found in the thorax, abdomen, and extremities are not arranged to antagonise each other, and that the flexors, pronators, and abductors do not when they shorten forcibly drag out the extensors, supinators, and adductors. On the contrary, it can scarcely be doubted that all these movements are co-ordinated and act conjointly as in the heart; the extensors, supinators, and adductors elongating when the flexors, pronators, and abductors shorten, and *vice versâ*: there being, in short, no such thing as antagonism in muscular movements. It does not follow that because one muscle is situated upon one aspect of a limb, and a second muscle upon another and opposite aspect of the same limb, that therefore the two muscles antagonise or contend with each other. When a muscle by its shortening is intended to stretch another substance, that substance as a rule is simply elastic, that is, it has no power of originating movement. We have examples of this in the smaller blood-vessels, and in the wing of the bird.

Fig. 183.

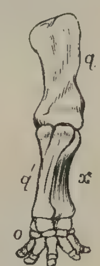


Fig. 184.

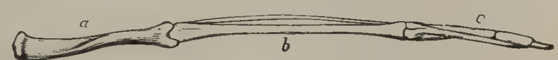


Fig. 185.

Fig. 183.—Photograph of a cast of the left ventricle of the heart of a deer. Shows the spiral nature of the left ventricular cavity. For further description see Fig. 176 (the Author, 1864).

Fig. 184.—Bones of the anterior extremity of the elephant. Shows the spiral arrangement of the bones of the fore-leg. Compare with Fig. 183. *q*, Humerus; *x*, *q'*, radius and ulna; *o*, bones of foot (the Author, 1872).

Fig. 185.—Bones of the wing of a bird. Shows their spiral arrangement. Compare with Figs. 183 and 184. The bones of the human arm resemble those of the fore-limb of the elephant and the wing of the bird. *a*, Humerus; *b*, radius and ulna; *c*, bones of the hand (the Author, 1872).

The chief function of the voluntary muscles is to move bones. To move bones effectually and avoid waste there must be conservation of energy. To conserve energy, the muscles of necessity act upon the bones to be moved and not upon each other. The muscles consequently are correlated and their movements co-ordinated. To say one muscle acts against another muscle, is equivalent to saying a muscle acts against itself, and of this we have no proof. In the penniform and other compound muscles, where the fibres meet at a variety of angles and tend to cross, all the fibres shorten and elongate simultaneously as in the different portions of the heart. In the muscular masses investing universal joints, such as are found at the shoulders and pelvis, precisely the same thing happens. The fibres, whatever their length, strength, and direction, act synchronously and to given ends, and by their united efforts produce an infinite variety of movements. These masses, in conjunction with similar masses in the extremities, can cause the bones to which they are attached to act spirally and to rotate and semi-rotate in a manner analogous to that by which the ventricles of the heart move during the diastole and systole. The movements in question account for the single and double figure-of-8 curves so well seen in the locomotion of the higher animals. The ventricles when they contract and rotate wring the blood out of their interior by a twisting screw-like movement in an unexpected manner, but which is nevertheless quite characteristic. The rotation of the ventricles is accompanied by a tilting of the apex which has considerable diagnostic value in cardiac cases.

Before leaving the subject of muscular arrangements, it may be useful to recapitulate very briefly.

In the smallest blood-vessels only one set of muscular fibres is present. In the larger blood-vessels two sets are found.[1] The same arrangement obtains in the intestine, the muscular tunic of the worm, and many simple

[1] In some of the larger veins, there are two sets of muscular fibres; the one running in the direction of the length of the vessel, the other across it. Thus in addition to the circular fibres always present in the central layers, there are longitudinal fibres mixed up with the areolar tissue and longitudinal elastic fibres of the external layer, which extend the whole length of the inferior vena cava, the renal, azygos, and external iliac veins, and in all the large trunks of the portal venous system, and in the trunks of the hepatic veins. Muscular tissue is also

structures. In the ventricles of the heart, the stomach, bladder, uterus, thorax, abdomen, and the extremities, the muscular fibres are arranged at right angles to each other and obliquely; but always in pairs and symmetrically. The muscles of the tongue afford a good example. In this organ the fibres of the intrinsic muscles practically run in all directions. Thus there are fibres which traverse the tongue from side to side; others which traverse the tongue from above downwards or vertically. Between these two sets of fibres, which intersect each other at right angles in different planes, there are others, which converge towards the axis of the organ, and which intersect or tend to intersect at gradually increasing angles, but always in pairs, as in the heart. To these are to be added a sheathing of fibres which invest the tongue in the direction of its length. The universality of the movements of the tongue is well known, and can be seen to advantage in a great number of animals, especially the chameleon. The tongue certainly possesses an inherent power of elongating and shortening; indeed in many of the ruminants it takes the place of a hand, and in browsing alternately seizes the grass first on the right and then on the left side. When the tongue elongates, its cross fibres shorten and broaden; when the tongue shortens its longitudinal fibres broaden. The action of the tongue affords an example of simultaneous co-ordinated movements. The muscles situated at the root of the tongue are arranged on a similar principle; these, when they elongate, pushing out the tongue, and when they shorten, drawing it in. This follows because the major portion of the muscles of the tongue have imperfect osseous attachments, being fixed only at one end, and possessing great freedom of movement at the other.

STRUCTURE AND PROPERTIES OF VOLUNTARY AND INVOLUNTARY MUSCLES

The voluntary and involuntary muscular systems at first sight appear to have few things in common. In reality they have many; the one being a modification or differentiation of the other. The common parent of the involuntary and voluntary muscle is the nucleated cell, and to this both may be referred.[1]

§ 151. Involuntary Muscle.

The fibres of the involuntary muscles are non-striated or unstriped, that is, they possess no transverse markings. They consist of elongated spindle-shaped fibre-cells, which are flat, clear, granular, and brittle, so that they break off suddenly, and present a square extremity. Many of them display a rod-shaped nucleus in their interior. They occur in the arteries, lymphatics, stomach, intestine, bladder, the pregnant uterus, the ducts of glands, the gall-bladder, vesiculi seminales, &c.

§ 152. Voluntary Muscle.

The fibres of fœtal voluntary muscle display in their substance the nuclei of the cells from which they are developed (Fig. 186, B, *a*, *a*); these corresponding to the rod-shaped nuclei of the involuntary muscle (Fig. 186, A, *a*). The striæ are very faintly marked (Fig. 186, B, C). The fibres of the adult voluntary muscles, on the other hand, are distinctly striated or striped, that is, they display a series of symmetrical, longitudinal, and transverse markings, as shown at Fig. 186, D, E, F, G, H, I. As emphasising the points common to involuntary and voluntary muscles it should be stated that there are mixed muscles which occupy an intermediate position, and which, strictly speaking, are neither involuntary nor voluntary.

A voluntary fibre consists of an aggregation of square particles arranged with great regularity in symmetrical rows (Fig. 186, D, H). Each fibre is covered by a thin, transparent, elastic membrane, the sarcolemma, which isolates the one fibre from the other (Fig. 186, E, *a*). The involuntary fibre is not invested with this membrane. The voluntary differs from the involuntary fibre in being of a cylindrical shape.

abundantly developed in the veins of the gravid uterus, being found in all three coats, and in the venæ cavæ and pulmonary veins it is prolonged on to them from the auricles of the heart. Muscular tissue is wanting in the veins of the maternal part of the placenta, in most of the cerebral veins and sinuses of the dura mater, in the veins of the retina, in the veins of the cancellous tissue of bones, and in the venous spaces of the corpora cavernosa. ("Anatomy, Descriptive and Surgical," by Henry Gray, F.R.S., &c., p. 401.)

[1] The researches of Valentine and Schwann have shown that a muscle (voluntary) consists in the earliest stages of a mass of nucleated cells, which first arrange themselves in a linear series with more or less regularity, and then unite to constitute the elementary fibres. As this process of agglutination of the cells is going forward, a deposit of contractile material gradually takes place within them, commencing on the inner surface and advancing to the centre till the whole is solidified. The deposit occurs in granules, which, as they come into view, are seen to be disposed in the utmost order *in longitudinal and transverse rows*. From the very first period these granules are part of a mass, and not independent of one another. The involuntary fibres are apparently homogeneous in texture. They, however, in some cases, present a mottled granular appearance, the granules being arranged in a linear series. This condition Bowman is inclined to regard as an approximation towards the structure of the striped or voluntary fibre; the granules being of about the same size as those in the voluntary fibres. In the simple muscles of the lower animals, consisting in some cases of only one or two rows of sarcous elements, a transition from the striped towards the unstriped fibres may be perceived; the transverse markings under these circumstances being irregular, broken, or faintly marked.

Much confusion unfortunately exists as to the ultimate composition of the voluntary muscles, and the nature of the striation. Some are of opinion that the elementary particles of which a fibrilla is composed consist of rows of corpuscles or discs connected by a homogeneous transparent material; others believing that they consist of little masses of pellucid substance, possibly nucleated cells, which, because of the pressure to which they are subjected, present a rectangular outline, and appear dark in the centre. Bowman, who has devoted much attention to this subject, describes and figures a longitudinal and transverse cleavage (Fig. 186, I, F). He says, "Sometimes the fibre will split into discs only (Fig. 186, F, *c*, *d*); more often into fibrillæ only (Fig. 186, I, *b*); but there are always present in it the transverse and the longitudinal lines which mark the two cleavages" (Fig. 186, I, *a*). He delineates two fibrillæ, in one of which the borders and transverse lines are all perfectly rectilinear, and the enclosed spaces perfectly rectangular (Fig. 186, H); in the other, the borders are scalloped, and the spaces are bead-like (Fig. 186, G). When most distinct and definite the fibrilla presents the former of those appearances. The ultimate particles, or sarcous elements, as they have been termed, are merely indicated when the fibre is entire; the dark and light squares being blended together and forming a continuous structure. It is only when the fibre is injured, and partly disintegrated, that the alternate squares can be seen to advantage (Fig. 189, p. 539). The squares in question exist under all circumstances; their number and form being imprinted in the very structure of the fibre in its perfect state. In virtue of the longitudinal and transverse cleavage which takes place, a muscle may be separated into its longitudinal fibrillæ and transverse discs. "To detach a fibrilla entire is to remove a particle from every disc, and to take away a disc is to abstract a particle of every fibrilla." The dark and light markings are due not to an actual difference in colour in the sarcous elements, but to unequal refracting power. This can be shown by altering the focus of the microscope; the dark and light lines being by this means made to change places. Some aver that in living muscle no lines are visible; but the fact that the dead muscle coagulates and disintegrates, or breaks up into square patches, tends to prove that the sarcous elements differ in some way from the material which connects them, and that there are at least two substances in an ultimate muscular fibre. I direct attention to the sarcous elements so admirably described and figured by Bowman, because I think they furnish us with a means of explaining the manner in which voluntary and involuntary muscles shorten and lengthen.

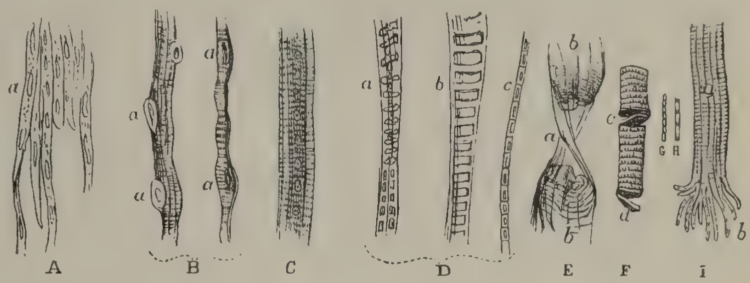


FIG. 186.—A. Unstriped elementary fibres from human colon: treated with and without acetic acid.

B. Elementary fibres from pectoral muscle of fœtal calf, two and a half months old, showing corpuscles *a*, *a*, magnified 300 diameters.

C. Elementary fibres from larva of dragon-fly, in an early stage of development, showing central row of corpuscles, magnified 300 diameters (Bowman).

D. Muscular fibrils of pig, magnified 720 diameters. *c*, Single fibril, showing quadrangular outline of component particles, their dark central part and bright margin and their lines of junction crossing the light intervals; *b*, longitudinal line of fibre, consisting of a number of fibrils still connected together; *a*, other smaller collections of fibrils (from a preparation by Mr. Leatham, after Dr. Sharpey).

E. Fragment of an elementary fibre of the skate, held together by the untorn and twisted sarcolemma. *a*, Sarcolemma; *b*, *b*, opposite fragments of the fibre.

F. Fragment of striped elementary fibres, showing transverse cleavage (*c*, *d*) of sarcous elements. The longitudinal cleavage is seen at *b* of I.

G, H. Appearances presented by the separated single fibrillæ. At G the borders are scalloped and the spaces bead-like. At H the borders and transverse lines are all perfectly rectilinear, and the included spaces perfectly rectangular. The latter is the more common (after Bowman).

§ 153. Mixed Muscles.

Between the involuntary and voluntary muscles are a mixed class which run the one into the other by gentle gradations. Thus the mammalian heart, the lymphatic hearts of reptiles and birds, the stomach and intestines of some fish, and the upper part of the œsophagus, are all involuntary muscles, and yet they possess the transverse markings distinctive of the voluntary muscles. The movements of the voluntary and involuntary muscles likewise run into each other. Thus "many involuntary movements are performed by muscles which are subject to the will; and many muscles that are commonly independent of the will are liable to be affected by it or by other acts of the mind. More than all, whether a muscle is involuntary or not, depends not on itself, but on the nervous system; for if the brain be removed or inactive, all the muscles become involuntary ones."

Muscles endowed with Centrifugal and Centripetal Movements—Sarcous Elements of Muscle—Their Peculiar Action.

The first fact to be fixed in the mind when attempting to comprehend the action of a muscle, is the remarkable one, that when a muscle contracts or shortens, it bulges out laterally, and elongates transversely. This follows, because when a muscle acts, its volume remains always the same.

In order that a muscle may shorten in the direction of its length and elongate in the direction of its breadth, and the converse, its ultimate particles, whatever their shape, must have the power of acting in two directions, namely, in the direction of the length of the muscle, and across it.

§ 154. Muscular Motion as bearing on the Functions performed by the Heart, Blood-vessels, Thorax, Extremities, &c.

With a view to forming a just estimate of the manner in which muscles act, it is necessary to take a wide survey of those substances which we know are capable of changing shape, and which take part in locomotion and other vital manifestations. This becomes especially necessary when we remember that some physiologists maintain that even the striation in voluntary muscles is due not to the presence of two substances, but simply to unequal refraction and the play of light. The advocates of this view regard the substance of voluntary muscle as homogeneous; the dark and light sarcous elements or squares constituting the longitudinal and transverse striæ being in their opinion all of the same colour. The striæ, as stated, are absent in involuntary muscles, and very faintly indicated in young voluntary muscles, so that we must not lay too much stress on the transverse markings, which may, after all, be an optical delusion. When I employ the term sarcous element, cube, or square, I wish it to represent a definite portion of the muscular mass having that particular form. The dark and light sarcous elements may or may not have exactly the same chemical constitution, but this does not interfere with the property which both possess of changing shape, and this it is which distinguishes muscular and all other forms of movement occurring in the tissues. The movements of the voluntary and involuntary muscles are in some senses identical. As voluntary muscle is a development and differentiation of involuntary muscle, so voluntary movements are to be regarded as higher manifestations of involuntary movements. In the involuntary muscle there is a recognisable structure (Fig. 186, A, p. 535), and in the voluntary muscle that structure apparently becomes more elaborate (Fig. 186, D, p. 535); but movements definitely co-ordinated, and very precise in their nature, can occur in tissues which are structureless or homogeneous; and this is a point not to be overlooked when studying the movements of the voluntary and involuntary muscles, for it shows that structure, in the ordinary acceptation of the term, is not necessary to motion. Thus, the amœba, which consists of a soft jelly mass, can change its shape in any direction it pleases. It can, as I have ascertained from actual observation, push out or draw in a knuckle of any part of its body. These movements are not due to contraction in the ordinary sense of the term, for the portion of the body protruded is wedge-shaped; no trace of constriction being anywhere visible. They are doubtless referable to a centripetal and centrifugal power inhering in the protoplasmic mass which enables the creature to advance or elongate, and withdraw or shorten, any part of its body. At times the amœba elongates its entire body by a wave-like movement, after which it sends out lateral processes which exactly correspond with the bulgings produced on a muscular fibre when it is made to contract or shorten under the microscope. When it sends out the lateral processes or elongates in the direction of its breadth, the body of the animal is shortened. When the lateral processes are shortened, the body of the animal is elongated. The analogy between the movements of an amœba and those of a muscular fibre, or a portion thereof, is therefore complete. Indeed there is every reason to believe that the movements of the amœba and of the sarcous elements of a muscle are identical. Both can change their form, elongation in one direction entailing shortening in another and opposite direction. In either case change of form does not involve change of volume, this always remaining exactly the same. Similar properties are possessed by the mushroom-shaped disc of the medusa. This consists for the most part of a jelly mass. The animal advances by a deliberate opening and closing of its disc; these movements, as I have fully satisfied myself from an attentive examination of living specimens, being quite independent of each other. The disc opens slowly and closes rapidly, as in the heart; the disc when it closes forcing itself from the surface of a fluid wedge with considerable energy. Here the centripetal and centrifugal power which I am disposed to claim for muscle, and especially for hollow muscles—such as the heart, stomach, bladder, uterus, blood-vessels, &c.—is seen to perfection. When the disc closes, the substance of the animal converges and seeks the centre; when the disc opens, its substance diverges and flies from the centre. The closing movement is the result of a vital converging, closing, or shortening of all the particles composing the body; the opening movement being the result of a vital diverging, expanding, or elongating of the same particles. This follows because the fluid in which the medusa is immersed can take no part

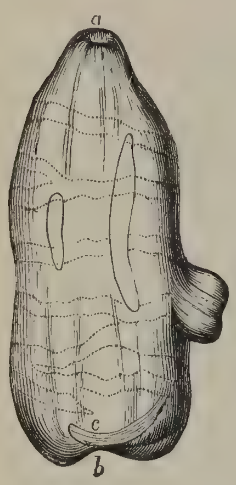


Fig. 187.—*Salpa cristata*. *a*, Orifice at mouth; *b*, orifice corresponding in situation to anal aperture; *c*, valve guarding orifice *b*, which permits water to enter in the direction of the mouth, but prevents its return in an opposite direction. (Cyc. of Anat. and Physiol.)

either in the closing or opening of the disc. The movements of *Salpa cristata* still more closely resemble those of the heart (Fig. 187, p. 536). The salpa may very properly be compared to the left ventricle. Thus it is a conical-shaped bag supplied with two apertures; one of which, situated at the extremity of the animal (*b*), corresponds to the auriculo-ventricular orifice; the other, situated at the mouth (*a*), to the orifice of the aorta. The orifice corresponding to the auriculo-ventricular opening is supplied with a valve (*c*) which may be compared to the mitral valve. When the animal wishes to advance, it expands, and draws or sucks water into its body by an aperture furnished with the valve. It then by a centripetal movement closes its body and the valve, and by so doing forces the water out of its interior at the aperture which corresponds to the orifice of the aorta. By this expedient the salpa confers on its body a retrograde movement. The fact to be attended to in the movements of this simple creature is the power it possesses of expanding and drawing water into its interior, which it subsequently forcibly ejects. It thus exerts a pulling and a pushing power, similar to that exercised by the left ventricle or any other compartment of the heart.

The centripetal and centrifugal movements adverted to are not confined to animals, and we must descend still further in the scale of being if we would see them in their most rudimentary forms. They occur in such plants as the *Volvox globator* and *Chlamydomonas*, the vacuoles of which open and close with time-regulated beat.[1] They are the same which cause the leaves and flowers of certain orders of plants to open and close at various periods of the day and night. If, therefore, structureless masses have the power of opening and closing, or, what is the same thing, of elongating and shortening, it is not too much to claim a similar power for a muscular fibre and the sarcous elements of which it is composed; the more especially as we know from observation and experiment that the muscular fibre when it shortens in one direction elongates in another direction, the fibre and its component particles possessing the power of abandoning and returning to their original form. If it be true that when a muscle shortens it elongates in the direction of its breadth, and if further it be true that when a muscle elongates it shortens in the direction of its breadth, it follows that all the particles in the mass obey the same laws. Thus when a muscle shortens in the direction of its length, all its particles, whatever be their composition, colour, or original form, elongate in the direction of the breadth of the muscle. When, on the other hand, a muscle elongates in the direction of its length, all its particles shorten in the direction of the breadth of the muscle. But the particles of a muscle are free to change shape in any direction, for it is well known that if a long muscle be artificially stimulated it shortens and after a while regains its original dimensions, so that by repeating the stimulus it may be made to shorten a second time. This happens even when the long muscle is cut away from its connections, and when it is removed from the influence supposed to be exerted upon it by what is termed its antagonist muscle. This tends to prove that the power which all muscles possess of alternately shortening and elongating inheres in their substance or sarcous elements, the movements being essentially vital in their nature, and independent of each other. That a muscle or muscular fibre, or their component particles, are endowed with universality of motion, is apparent from the fact that when a muscle or a muscular fibre shortens, it is thrown into rugæ or swellings, the long axes of the particles of the swelled portions being arranged at right angles to the long axes of the particles representing the constrictions or narrow parts. But those parts of the muscle or fibre which form the constrictions the one instant become the swellings the next, the direction of the long axes of the particles or sarcous elements of the muscle or fibre being in this case reversed. Muscular movements are therefore the result of a rhythmic motion in their ultimate particles, in all respects analogous to the rhythmic movements of the heart. The movements of muscles are characterised by two forces acting at right angles to each other; the one force flying a fixed point, while the other seeks it (Fig. 188).

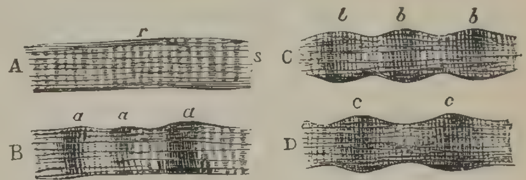


FIG. 188.—Shows an elementary fibre of the skate in the uncontracted and contracted state.
A. Fibre in the condition of rest. *r*, Transverse markings or cleavage; *s*, longitudinal markings or cleavage.
B. *a*, *a*, *a*, One side of fibre contracting or shortening.
C. *b*, *b*, *b*, Both sides of fibre contracting or shortening. All parts of the fibre become involved in succession. Thus, the constriction between *b*, *b*, *b* of C become the swellings *c*, *c* of D (after Bowman).

In reality the ultimate particles or sarcous elements of a muscle are correlated and definitely co-ordinated, neighbouring particles or groups of particles exercising a centrifugal and centripetal power which causes one set of particles to advance in one direction, while a corresponding set recede in an opposite direction. This is what virtually happens in the voluntary system of muscles. When one muscle shortens on one side of a limb, that on the opposite side elongates. By assigning a centrifugal and centripetal power to moving masses, we can readily understand how structureless tissues open and close. Without such a power even complex tissues would have

[1] That a jelly-like mass, apparently devoid of structure, is capable of shortening and elongating, is proved by a very remarkable experiment made by Kühne. This distinguished physiologist took the intestine of a cockchafer and stuffed it with living protoplasm from a living plant. He applied electricity to the gut so prepared, and found, to his surprise, that it exhibited all the phenomena peculiar to muscle when artificially stimulated—the intestine shortening suddenly when the stimulus was applied, and elongating slowly after it was withdrawn.

difficulty in moving. From the foregoing it follows, that from the time the particles of a muscle leave their position of rest and begin to change their form until they return to their original position and assume their original shape, they are in a state of activity. This is proved by the fact that when a muscle or sarcous element shortens in the direction of its length, it broadens or lengthens in the direction of its breadth, and *vice versâ*. If we assign to muscles, or their sarcous elements, the power of changing shape in one direction, it is unphilosophic to assume that they have not the power of changing shape in another and opposite direction. Even structureless masses of protoplasm are endowed with this double power, and the amœba, which may be regarded as an aggregation of such masses, can elongate and shorten its body with equal facility, can contract or close in one direction and expand or open in another—can make a temporary cavity in its substance to serve the purpose of a temporary stomach, and then obliterate it. Similar attributes inhere in the white blood-corpuscle. The majority of physiologists of the present day deny that muscles are endowed with the power of elongating. They say that muscles can only contract or shorten, and that when they elongate their elongation is due to elasticity, or they are drawn out by antagonist muscles ; a flexor drawing out its extensor the one instant, the extensor drawing out the flexor the next. If this were so, the muscles, as already indicated, would act upon and against each other, instead of upon the bones they are intended to move. The waste of muscular energy under such circumstances would be enormous. The prevailing theory of muscular action is thus stated by Bowman : "The contraction of a muscle will be permanent if no force from without be exerted to obliterate it by stretching, for a contracted muscle has no power of extending itself." Much of the obscurity regarding muscular movements is, I believe, traceable to the employment of the terms *contraction* and *relaxation*, contraction primarily signifying a shrinkage or diminution in volume, which does not occur in muscular movements ; relaxation, an abandonment of the contracted state. An example may be useful. According to prevailing opinions a flexor, when it contracts or shortens, drags out or elongates its extensor ; the flexor being *active*, the extensor *passive*. Another way of putting it is this : When the flexor *contracts* the extensor *relaxes*, that is, offers no opposition to being drawn out by the flexor. This, however, is avoiding the difficulty by taking refuge in terms. Either a muscle (or parts thereof) is or is not active. When it is not in a state of activity, it is in the condition of rest, so that the phrase *passive contraction*, so frequently employed, has no meaning. I propose, therefore, for these and other reasons, to abandon the terms *contraction* and *relaxation*, as being inapplicable to muscular movements, and to substitute for them the more simple ones of *shortening* and *elongating*, as applied to long muscles ; and *closing* and *opening*, as applied to hollow muscles. By the shortening or closing of a muscle, I mean its centripetal action, that action by which its particles converge and crowd towards a certain point ; by the elongating or opening of a muscle, I mean its centrifugal action, that action by which its particles diverge or escape from a certain point. These movements are not equally rapid, but they are equally independent and vital in their nature.[1]

That muscles possess a centripetal and centrifugal power—that is, a power by which they alternately shorten and elongate—and that one set of muscles is never employed for violently pulling or drawing out or elongating another set, is abundantly proved by the action of the heart, and the hollow muscles with sphincters, such as the stomach, bladder, rectum, uterus, &c. The heart pulsates in the embryo while yet a mass of cells, and before it is provided either with cavities, blood, or muscular fibres. The different compartments of the heart open and close after the organ is cut out of the body, and when it is deprived of blood ; but the deprivation of blood prevents the auricles acting upon the ventricles, and the ventricles upon the auricles. The auricles and ventricles are to be regarded as anatomically and functionally distinct. That the auricles when they close do not forcibly distend or open the ventricles, is evident from the fact that the ventricles open and close spontaneously when the auricles are removed. Further it occasionally happens when the heart is intact, *in situ*, and acting slowly, that the ventricles open before the auricles close. Finally the ventricles, which are very powerful structures, obliterate their cavities when they close, so that the auricles, which are very feeble structures, have not the requisite power to force the blood which they contain into the solid muscular mass formed by the ventricles at the termination of the systole. The obliteration of the left ventricular cavity of the heart of the deer is well seen in transverse section in Plate xcvii., Fig. 11.

If the ventricles (involuntary muscles) can open and close in parts simultaneously but in opposite directions, there is no reason why the muscles of the trunk and limbs (voluntary muscles) should not also open and close in

[1] Dr. Martin Barry endeavoured to explain muscular actions by assuming that the sarcous elements were arranged as in a spiral spring ; but neither the disposition of the dark and light squares, nor their mode of action, favours this view. The late Professor Alison attributed the contraction and relaxation of muscle to the attraction and repulsion of its ultimate particles. Thus he states that contraction essentially consists in a greatly increased attraction among the particles or globules constituting the muscular fibres, and alteration in the direction in which the attraction acts, rapidly communicating from one particle to another, both along the same fibre and among adjacent fibres, and rapidly succeeding by repulsion or return to the previous state of cohesive attraction existing among those particles ; and Dr. C. B. Radcliffe (*Nature*, Jan. 2, 1872) expresses a belief "that living muscle is kept in a state of elongation by the presence of an electrical charge, and that contraction is nothing more than the action of the fibres, by virtue of their elasticity, when liberated by discharge from the charge which kept them elongated previously." Matteucci had come to a similar conclusion at an anterior date, and expressed his belief that muscular action is accompanied by a discharge of electricity analogous to that of a torpedo. This view, Dr. Radcliffe adds, has received confirmation from the new quadrant electrometer.

parts simultaneously in opposite directions. The muscular system is here regarded from a new but, it appears to me, important standpoint, and I earnestly recommend the new view to the careful and favourable consideration of my readers.

That the ventricles do obliterate their cavities when they close is a matter of observation. Ever and anon, when making post-mortem examinations at the Royal Infirmary of Edinburgh, I found the ventricles pursed and rolled together in the form of a solid ball. Even the stomach is endowed with the power of all but obliterating its cavity, and I have at present in my possession a human stomach, the body of which has a diameter not greater than that of the small intestine.[1] The movements of the hollow muscles with sphincters strongly support the view that muscles have the power of simultaneously elongating and shortening; in other words, have a centrifugal and centripetal action which enables them to act in parts or separately, and as wholes or conjointly. When the stomach, bladder, or rectum close, their sphincters open, and *vice versâ*. But the closing of the stomach, bladder, and rectum is occasioned by the simultaneous closing, shortening, and broadening of all (or nearly all) the fibres composing the bodies of the viscera; the opening of the sphincters being occasioned by the simultaneous opening and elongating of all the fibres which go to form the sphincters. As the sphincters are powerful structures which guard narrow apertures, and the bodies of the viscera are comparatively feeble, it follows that no effort on the part of the bodies of the viscera, acting upon their fluid or semi-fluid contents, could force a passage. Such force is not required, as the sphincters open spontaneously when the bodies of the viscera close. The movements are co-ordinated in the same way that the movements of the different parts of the heart or those of the flexor and extensor muscles are co-ordinated. These movements are, however, only possible in structures which alternately open or elongate, and close or shorten; that is, exert a centrifugal and centripetal power. The simultaneous centrifugal and centripetal movements of the hollow viscera throw a flood of light on the movements of the several sets of so-called antagonist muscles, and should be carefully pondered.

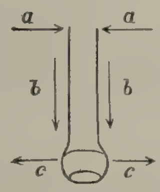


FIG. 189.

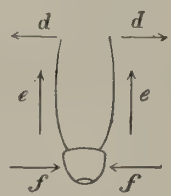


FIG. 190.

FIG. 189.—Shows how the rectum closes and the sphincters open to discharge the fæces. In the act of defæcation the rectum closes, and narrows in the direction *a*, *a*, and elongates in the direction *b*, *b*; the sphincters opening and widening in the direction *c*, *c*. The darts indicate the direction in which the forces engaged in discharging the fæces operate. The assistance derived from the co-operation of the abdominal muscles is not estimated (the Author, 1872).

FIG. 190.—Shows how the rectum opens to receive the fæces, and how the sphincters close to prevent their escape. In this case the rectum opens in the direction *d*, *d*, and shortens in the direction *e*, *e*; the sphincters closing in the direction *f*, *f*. Here the darts indicate the direction in which the forces act to retain the fæces (the Author, 1872).

The opening and closing of the rectum and its sphincters are represented at Figs. 189 and 190.

Much confusion has arisen from classifying the muscles (voluntary) into flexors and extensors, &c.; the flexors occurring on one aspect of a limb, the extensors on the other and opposite aspect. It was believed that the muscles referred to were opposed to and antagonised or worked against each other. Now there could be no greater fallacy than this. Nature never works against herself. The voluntary muscles—whether flexors and extensors, or abductors and adductors, or pronators and supinators—form cycles; one segment of the cycle being placed on one side of the bones to be moved, the remaining segment of the cycle on the opposite side of the bones. When the one side of the cycle closes or shortens, the opposite side of the cycle opens or elongates. Muscular energy is thus conserved to the utmost, and the bones are made to vibrate within their muscular cycles with marvellous precision and exactitude. But for this arrangement the delicate manipulations required in the manufacture of watches, philosophical instruments, &c., could not be performed. The opening and closing, say of the flexor and extensor arcs of the cycles, are in all respects analogous to the opening and closing movements which occur in the different parts of the heart and in the hollow muscles with sphincters. It is thus that the movements of the voluntary and involuntary muscles may be assimilated and referred to a common source.

The involuntary hollow muscles supply the type or pattern on which the voluntary muscles are formed. Nor is this all. In idiots whose nervous system is deranged, the involuntary movements return in the voluntary muscles; and it is by no means an uncommon thing to see in our large lunatic asylums poor demented creatures exhibiting rhythmic movements in different parts of their persons. Thus a considerable number of patients are found who for hours together move their head, trunk, or limbs backwards and forwards, or laterally, with a steady see-saw motion, automatically and unconsciously. I was particularly struck with these rhythmic movements in voluntary muscles on a visit to the West Riding Lunatic Asylum, where owing to the courtesy of my distinguished friend, Dr. (now Sir James) Crichton Browne, the medical superintendent of the institution, I had an opportunity of studying them under unusually favourable conditions.

[1] The patient to whom this stomach belonged died of inanition, occasioned by stricture of the œsophagus. The stomach itself is quite healthy.

I am well aware that elasticity is assigned a high place in muscular movements by modern physiologists, but there are grounds for believing that its power has been greatly overrated; the sarcous elements, of which muscles are composed, being arranged to act either with or without elastic substances.[1]

Elasticity is to be regarded as an auxiliary of muscular manifestations, a modification to confer continuity of movement. All muscular movements are interrupted movements. Muscles act singly or in pairs, first in one direction, and then in another. In order that muscles may reverse their movements, they are endowed with a certain amount of elasticity to assist them over their dead points. That, however, elasticity is quite a secondary matter is evident from this: elasticity cannot generate a movement, muscular movements beginning and terminating in the muscles themselves. Elasticity is to a prime mover (such as a muscle) what an echo is to a sound. It repeats, or tends to repeat, movements generated without or beyond the substance in which it inheres. The blood-vessels are endowed with a greater share of elasticity than the hollow muscles and involuntary muscles generally, the involuntary muscles having a greater share than the voluntary ones. In proportion as muscles become differentiated, and their movements exact, their elastic properties disappear. By assigning a double centripetal and centrifugal action to muscles, as apart from elasticity and antagonism, we secure to the muscles, and the sarcous elements composing them, absolute rest when they are not engaged in shortening or lengthening. There is no necessity for supposing, as hitherto, "that muscles are kept upon the stretch by the nature of their position and attachments, and by a state of *passive contraction* which opposes their elongation by antagonists." It is more natural to assume that the muscles which form opposite sides of muscular cycles, instead of maintaining their relative positions by a state of passive contraction, as it is termed, are simply in a state of inaction. By assigning, as I have done, to the muscles and their sarcous elements the power of acting in two directions at right angles to each other, we get rid of the passive contraction of authors, and the necessity for one muscle or sarcous element, when it shortens, dragging out another muscle or element which has been regarded as its antagonist, but which in reality is its correlate. It is impossible to understand how a muscle can be resting in a state of even passive contraction. A healthy muscle is firm in absolute inaction, but its hardness is not due to passive contraction. A muscle enjoys a greater degree of repose than is usually imagined. It is in a state of absolute rest when not shortening or elongating. But the sarcous elements of a muscle, even when shortening and elongating, have intervals of repose, from the fact that they do not all act at once, but alternately and successively. As a muscle moves in its ultimate elements, so it rests therein. This explains how the heart can go on without pausing as long as life lasts; how a muscle during its action produces a sound, the so-called susurrus; and how it develops heat, the ultimate particles triturating each other as they advance or recede.

§ 155. This Section shows how the Muscular Fibres open and close the Blood-vessels and the several Compartments of the Heart—also how the Stomach, Bladder, Thorax, and Abdomen open and close as wholes or in parts.

In the smallest capillary vessels no muscular fibres are to be detected. In the larger capillaries faint traces of circular fibres make their appearance. It is only in the smaller arteries and veins that a circular layer of muscular fibres becomes well marked. Every vessel furnished with circular muscular fibres can open and close. When the circular muscular fibres shorten, they elongate the vessel and diminish its calibre. When they elongate, they shorten the vessel and increase its calibre. This follows because the circular fibres form rings, and any change in their shape produces either an elongation and narrowing of the vessel, or a shortening and widening thereof (Fig. 194, p. 543). The circular fibres are capable of acting by themselves, or in conjunction with elastic structures arranged mainly in the direction of the length of the vessel. When elastic structures are present they are stretched when the circular fibres shorten. As elastic structures tend to regain their original form when the force which extended them has ceased to act, they assist the circular fibres in elongating. They confer rapidity and continuity of movement by assisting the muscle over its dead points: muscle, of necessity, acting first in one direction and then in another.

In the larger vessels a longitudinal layer of muscular fibres is added to the circular one. Under these circumstances, the two sets of fibres are arranged at right angles, and work together. When the vessel is to be narrowed and elongated, the circular fibres shorten and the longitudinal ones lengthen; when it is to be widened and shortened, an opposite condition prevails. The two sets of fibres take part in both movements, and do not antagonise or act against each other (Fig. 195, p. 543). The same thing happens in the vermicular movements of the intestine and the creeping of the earthworm (*Lumbricus agricola*), to which they are likened. The muscular tunics of the

[1] When the sarcous elements have departed as far as they can from their original shape and position of rest, elasticity assists the particles in reversing their forces, and gives continuity of motion. The elementary particles may be said to vibrate, and elasticity is calculated to help them over their dead points.

intestine and of the worm are composed of longitudinal and circular fibres, so that they exactly resemble certain of the blood-vessels. I have studied the movements of the worm with considerable attention, as being likely to throw some light upon similar movements in the vessels. Prior to moving, the earthworm draws itself together, and shortens and thickens its whole body (Fig. 191, A). It then elongates and narrows, telescopic fashion, the first inch or so (Fig. 191, B, *a*). In this movement the rings representing the circular fibres are separated from each other and thickened, the part moving being of a paler colour than the rest of the body. This shows that while the circular fibres shorten and broaden, the longitudinal ones lengthen and narrow, both sets of fibres taking a nearly equal share in the work. The power possessed by the worm of elongating a part of its body is undoubted. When the first instalment of the body is sent forward, it is gathered together and corrugated (Fig. 191, C, *a*), and securely fixed on the ground by the assistance of the setæ or hairs situated on the ventral aspect of the animal. A second inch or so is now elongated, telescopic fashion, and sent on precisely as in the first instance (Fig. 191, C, *b*). The second instalment is not drawn forward, as is generally believed, but pushed forward as described. When the second instalment is gathered to the first, and both fixed to the ground by the setæ, a third instalment is sent on, the worm not beginning a second step until the tail instalment is forwarded and added to the body. The worm advances by a peristaltic or wave movement. It pushes itself forward upon the ground, and in this respect resembles all other animals with terrestrial habits. If the worm had not the power of elongating and pushing its body forward, it is evident that it could never begin a step, as it would have no forward purchase (Fig. 191, B, *a*).

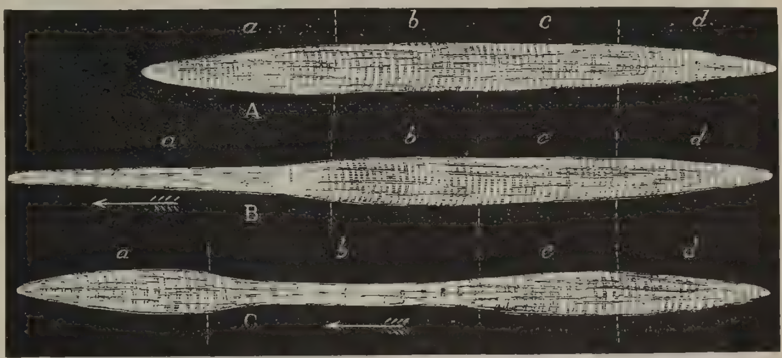


Fig. 191.—A. Represents the worm as drawn together prior to commencing a step, and divided into four equal portions, *a*, *b*, *c*, *d* (the Author, 1872).
B. Shows the first part of the worm as elongated or pushed out (*a*); the parts *b*, *c*, *d* acting as fulcra (the Author, 1872).
C. Shows the first part of the worm (*a*) shortened, corrugated, and fixed on the ground, the second part of the worm (*b*) being elongated or pushed out; the parts *c* and *d* acting as fulcra (the Author, 1872).

The movements of the worm are exceedingly interesting, as showing that a muscular mass composed of circular and longitudinal fibres (each set continuous upon itself) has the power of elongating even in the absence of fixed points. The locomotion of the worm is performed by two forces, which always act at right angles to each other. Thus, when the first part of the body is sent forward, the circular fibres exert their centripetal power, the longitudinal ones their centrifugal power. When this portion of the body is shortened and corrugated prior to being fixed on the ground by the setæ, the circular fibres exert their centrifugal power, and the longitudinal ones their centripetal power. The sarcous elements of the circular and longitudinal fibres alternately approach towards and recede from the centre of the moving parts. It follows from this that the part of the worm which is corrugating and broadening may be compared to a sphincter muscle which is opening; while that part of the worm which is elongating and narrowing may be compared to a hollow muscle closing. In these two movements, both of which are necessary to the locomotion of the worm, the elongating and shortening power possessed by muscle is clearly shown. One part of the worm elongates while another part shortens, and but for this consentaneous double movement (which is a co-ordinated rhythmic movement) no locomotion can take place. The same holds true of the voluntary muscles. When bones are to be moved, one part of the muscular cycle must shorten when the other elongates, and *vice versâ*. If any part of the worm attempted to shorten and lengthen at the same instant, it is evident that no locomotion would ensue. In like manner, if the voluntary muscles situated on one aspect of a bone or bones acted against the muscles situated on the opposite aspect, the bones would remain *in statu quo*. The commonly received opinion, that muscles have only the power of shortening, and cannot elongate, is, I believe, founded in error. The belief is no doubt traceable in a great measure to the incautious use of artificial stimuli. If, for example, electricity is applied to the first part of the worm when in the act of elongating, it instantly shortens. This, however, is no proof against the elongating power of muscle. It is simply the sudden substitution of an abnormal for a normal movement. If artificial stimuli produced natural movements they would, when applied to a muscle in the act of elongating, cause it to elongate more rapidly; in other words, they would quicken its movements, and in no instance check or reverse them. Muscle is not the only substance which shrinks or retires within itself on being assailed by a troublesome neighbour. The sensitive plant does the same.[1] The worm elongates its body on the withdrawal

[1] Desfontaines once carried a sensitive plant with him in a coach, with the following curious results. The jolting of the machine caused it at first to curl up its leaves. When, however, it became accustomed to the movement, it expanded them.

of the stimulus, and the sensitive plant regains its original shape. The return movements are therefore vital and normal. In the same way a muscle, when cut out of the body and made to shorten by an irritant, regains its original shape when the irritant is withdrawn, and may be made to shorten many times in succession. When the muscle returns to its original shape it elongates, the elongation being necessary to a repetition of the muscular movement. A long muscle when it shortens virtually reproduces the movements observed in the body of the worm when creeping, one part of the muscle swelling out or broadening by a centrifugal movement, while another portion thins or narrows by a centripetal movement. This accounts for a long muscle being thrown into *ampullæ* when it shortens (Fig. 188, C, D, p. 537).

Similar movements to those described in the worm occur in the tentacles of the Gastropoda. In murex, the tentacles are thick, solid, fleshy stems, composed of various strata of circular, longitudinal, and oblique muscular fibres. These are elongated and retracted at pleasure (Fig. 192). In the garden snail (*Helix pomatia*), the tentacles are hollow tubes, composed of circular bands of muscles. Within each tentacle is a long muscular slip (Fig. 193, *c*, *d*), extending between its free extremity and the common retractive muscles of the foot. When the muscular slip (*c*) shortens, the circular muscular fibres elongate, and the tentacle is invaginated (*a*). The same thing happens in invagination of the intestine. A reverse action takes place when the tentacle is protruded (*b*), the enclosed muscular slip (*d*) elongating, and the circular fibres shortening. That the evagination or protrusion of the tentacle is not due to the contraction or shortening of the circular fibres alone, is evident from this. If the tentacle is half invaginated (*a*), the shortening or closing of the circular fibres by themselves tends rather to invagination than evagination. To complete the process the longitudinal muscular slip (*c*) must elongate and push slightly.

Fig. 192.

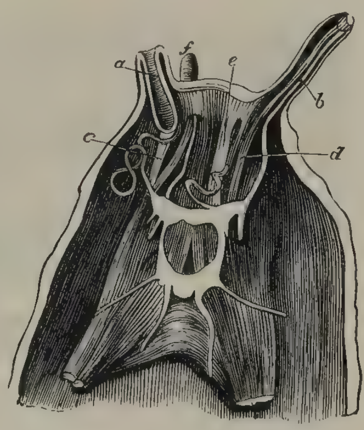


Fig. 193.

Fig. 192.—Shows tentacles of *Murex* (*a*, *b*) in elongated state (Adapted).

Fig. 193.—Shows the four tentacles of garden snail (*a*, *b*, *e*, *f*), one of which (*a*) is invaginated, and its muscle (*c*) shortened; a second one (*b*) being evaginated or pushed out, and its muscle (*d*) elongated (Adapted).

When a garden snail elongates its tentacles, we feel that the act is at once voluntary and vital. The moment, however, they touch a foreign body, they shrink.[1] The alarm passes away, and again the tentacles are cautiously elongated. The same thing happens in the sea-anemone. When this magnificent creature expands its tentacles like a gorgeous flower opening to the sunlight, it pushes them out with exquisite grace like so many microscopic telescopes. If, however, foreign matter be dropped into the water upon the anemone, the tentacles instantly retreat into the interior of the animal. The power of elongating and shortening possessed by the tentacles is, I believe, possessed by every muscle, by every one of its fibres, and by every one of its sarcous elements. If we grant to muscles the power of alternately shortening and elongating, we have an explanation of the multifarious movements which we behold in our own bodies. We can comprehend how the heart, blood-vessels, and hollow viscera act; how we are capable of migrating from one place to another; and how the hand is supplied with its cunning. All are vital manifestations. The elongation and shortening of the tentacles are analogous to the opening and closing of a compartment of the heart, the extending or flexing of the arm, or the protruding and retracting of the tongue.

To take another example: the mouth of the Gastropoda in most instances presents the appearance of a prehensile and retractile proboscis. This remark, I may observe, applies to the mouth and lips of a great many animals, the oval aperture and lips being pushed out and retracted at pleasure.

In the Gastropoda, which have no jaw or masticating apparatus, the movable proboscis consists of a muscular tube composed of longitudinal and circular fibres as in the intestine. By means of this simple structure, every possible kind of movement is effected, the tube seizing the food, and, by alternately opening and closing, forcing it into and along the alimentary canal, just as the blood is forced along a vessel endowed with rhythmic movements. The retraction of the proboscis is occasioned by the shortening of the longitudinal fibres, and the dilatation or elongation of the circular ones; the elongation being effected by a counter and contrary movement. The tongue, as has

[1] In phthisical patients, as Dr. Stokes has shown, a smart tap on a muscular part is followed by a contraction and swelling of the part struck. The part struck is surprised, and contracts or rolls itself together.

been stated, is also endowed with the power of elongating and shortening; the organ being employed by the ox for seizing the grass, and by the chameleon for securing insects.

By investing the sarcous elements of muscle with the power of shortening and elongating, longitudinal and circular fibres can be made to act by themselves or in combination, and so of every form of oblique fibres. If circular fibres are to act by themselves and diminish the calibre of a vessel, they shorten in the direction of the breadth of the vessel. If the same function is to be performed by longitudinal and circular fibres arranged at right angles, the circular fibres shorten in the direction of the breadth of the vessel, the longitudinal fibres elongating in the direction of its length. These movements are reversed if the vessel is to be widened. If a cavity is to be obliterated by longitudinal and circular fibres, the fibres shorten longitudinally and transversely. If it is to be opened, they elongate. If oblique fibres are present, they are accessories, and deport themselves in exactly the same way as the others. In hollow muscles the fibres require to be continuous upon themselves, and this accounts for the fact that in the heart, stomach, bladder, and uterus the fibres have neither origin nor insertion. The muscular apparatus and movements by which the smaller blood-vessels, intestine, stomach, bladder, ventricles, &c., are opened and closed are indicated at Figs. 194 to 200.

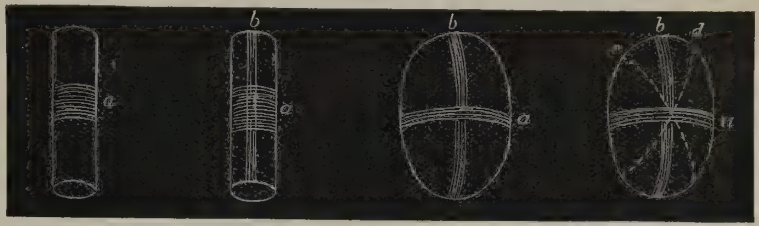


FIG. 194. FIG. 195. FIG. 196. FIG. 197.

FIG. 198. FIG. 199. FIG. 200.

FIG. 194.—Vessel supplied with circular or transverse fibres (*a*) capable of increasing or decreasing its calibre, and of shortening or elongating it (the Author, 1872).

FIG. 195.—Vessel supplied with circular (*a*) and longitudinal (*b*) fibres, capable of increasing or diminishing its calibre, and of shortening or elongating it (the Author, 1872).

FIG. 196.—Hollow muscle provided with circular (*a*) and longitudinal (*b*) fibres capable of increasing and diminishing its cavity so as to take in and eject fluid (the Author, 1872).

FIG. 197.—Hollow muscle provided with circular (*a*), longitudinal (*b*), and oblique (*c*, *d*) fibres, capable of opening and closing, and of taking in and ejecting fluid. In this case the opening and closing, because of the presence of the oblique fibres, is more perfect than in Fig. 196 (the Author, 1872).

FIG. 198.—Hollow muscle (human bladder) provided with circular (*a*), longitudinal (*b*), and oblique (*c*, *d*) spiral fibres, continuous at base (*b*) and apex (*e*) in which latter situation they form a sphincter. When the fibres constituting the body of the muscle close, the continuations of those fibres which form its sphincter open, and *vice versâ*. Such a muscle can receive, contain, and eject fluid (the Author, 1872).

FIG. 199.—Hollow muscle (left ventricle of heart of mammal) provided with circular (*a*), longitudinal (*b*), and oblique (*c*, *d*) spiral fibres, continuous at apex (*e*) and base (*b*). These fibres, by their united efforts, can open or close the muscle, and can cause it to suck in and eject the blood alternately (the Author, 1872).

FIG. 200.—Transverse section of left ventricle of heart (mammal), showing it in the open and closed condition. *v*, Ventricle when open; *w*, ventricle when closed, and cavity (*y*) obliterated; *x*, imaginary line, on either side of which the walls of the ventricle vibrate when the ventricle closes and opens, and when the ventricular fibres exercise their centripetal (*m*, *n*) and centrifugal (*o*, *p*) action (the Author, 1872).

The heart differs slightly from the blood-vessels, inasmuch as when it closes all its diameters are shortened; whereas, when it expands, all its diameters are elongated. In the opening and closing of the different compartments of the heart we have two diametrically opposite conditions. To produce this apparently impossible result in the ventricles, the fibres and the sarcous particles of the fibres are arranged vertically, transversely, and obliquely, in continuous spirals, as shown at Fig. 199. Fig. 200, *v*, shows a transverse section of the left ventricle of the heart in the expanded or dilated condition; *w*, of the same figure, showing a transverse section of the left ventricle when its cavity is obliterated. The darts *m*, *n*, *o*, *p* of Fig. 200 indicate the centripetal and centrifugal force possessed by the heart, in virtue of which it acts as a sucking and propelling organ. The heart has the power of forcibly expanding itself, as it has of forcibly closing itself. It can therefore, in virtue of its rhythmic movements, alternately suck in and eject blood—the auricles attracting it while the ventricles are repelling it, and *vice versâ*. When the walls of the ventricle travel beyond the circle represented by x of Fig. 200, in an inward direction, they push the blood out of the ventricular cavity; when they travel beyond the same circle in an outward direction, they suck the blood into it. A common caoutchouc bag, if filled with water, immersed in it, and squeezed at intervals, will do the same. The order in which the closure occurs in the vessels and hearts of the lower animals and in the heart of the mammal favours this view. In the cold-blooded animals the large veins (even to the venæ hepaticæ) close first; then the auricle or auricles, as the case may be; then the ventricle; and lastly the bulbus arteriosus. In the warm-blooded animals the terminations of the pulmonary veins and cavæ (superior and inferior) close first; then the auricles, then the ventricles,

and then the large vessels in the vicinity of the heart; these vessels, as already pointed out, being supplied with an elaborate plexus of nerves. The blood is, during its transmission, drawn into and seized by the large veins leading to the heart; then by the auricles, then by the ventricles, and then by the large arteries leading from the heart. No sooner, however, is it seized than it is dismissed, the seizure and the dismissal being alike necessary to the circulation. The blood is not permitted to wander about at pleasure in the cavities of the circulatory apparatus. On the contrary, it is made to flow in a continuous onward stream, by a series of very wonderful peristaltic movements, very much in the same way that the blood is forced into the alimentary canal of the leech by the simultaneous opening and closing in regular succession of the different portions of its muscular œsophagus. Nay more, it is made to open and close the valves or flood-gates which lead to and conduct from the chambers through which it passes. It is customary, when speaking of the action of the heart, to refer only to the closure of the organ, its opening being regarded as comparatively unimportant and depending indirectly on the closing. The opening of the heart, however, is as necessary to the circulation as its closing; and but for the fact that one part of the heart opens while the other closes, the blood could not be made to perform its endless round without quite an extravagant waste of power. The blood, like other fluids, is nearly incompressible, and if it is ejected from one place it must be received in another of nearly, I might safely say of exactly, the same dimensions. These are but so many proofs of arrangement and design. When the veins close, the auricles open; when the auricles close, the ventricles open; when the ventricles close, the arteries and veins open; and so on. The blood is alternately pushed and pulled. That the vessels may take a part in and modify the circulation is evident from the researches of Marey and Garrod, who show that any obstruction or narrowing in the small vessels slows the action of the heart.

§ 156. Analogy between the Movements of the Thorax, Abdomen, and Heart.

The primary function of the thorax is alternately to suck in and eject air; but it has a second function—it attracts or determines blood to the heart. In fact, the movements of the chest and heart are essentially the same, the object of both being to bring relays of air and blood into intimate contact within a given area. In breathing, the air does not simply rush into the lungs: it is drawn in by a vital act. It is likewise expelled by a vital act. In like manner the blood is drawn into the auricles and forced out of the ventricles by vital acts. This follows because the chest and heart have the power of alternately opening and closing. If the air rushed into the lungs mechanically, and was expelled thence by the mere elasticity of the lungs, we could not regulate the supply of air admitted into and sent from the lungs in inspiration and expiration. There would, moreover, be an absence of the rhythm which characterises the chest movements. We can arrest both the inspiration and expiration, which shows that these actions are voluntary and vital as well as involuntary and mechanical. That an intimate relation exists between the thorax and heart appears from this: by arresting the respiration, we can also arrest the circulation. M. Groux, who had a congenital fissure of the sternum, could arrest the pulsation of his subclavian and radial arteries by making a full inspiration, and then by holding his breath for a short interval. If he held his breath for a few moments after a full expiration, the pulsating tumour which appeared at the cleft sternum became larger, apparently from the heart becoming unusually distended with blood.

During inspiration the great veins entering and contained in the chest—namely, the subclavian, jugular, and superior and inferior cavæ—are full of blood, the blood being attracted by inspiratory effort. During expiration the vessels are comparatively flaccid. These changes are not confined to the chest; thus the radial pulse is weaker and less voluminous during inspiration, and stronger and more voluminous during expiration. The pulse is weakened during inspiration, from the fact that when air is inspired a large mass of blood is attracted to the chest, which has the effect of relieving the plethora of the arterial system—the blood being as it were dammed up in the arteries during expiration. The inspiratory and expiratory acts affect all the vessels of the body, the respiratory influence being most marked in the vessels of the head, chest, and trunk, and least in those of the extremities. This is rendered obvious by the fact that when the brain, which contains a very large number of vessels, is exposed, it is seen to shrink and recede during inspiration, and to swell out or expand during expiration. The attraction of the blood to the chest, and the consequent draining of the capillaries of the brain, sufficiently account for the diminution of its volume during inspiration; the absence of that attraction and the gorging of the capillaries accounting for the opposite condition during expiration. The rise and fall of the brain here referred to is not to be confounded with similar but minor changes induced by the action of the heart itself, as the two sets of phenomena occur at different periods. The celebrated Hales made this a matter of experiment. By causing the blood of horses and dogs to enter a vertical graduated tube, he found that with each beat of the pulse the hæmostatic column rose and fell two, three, or four inches; but that when the animals respired deeply or struggled, it rose and fell from twelve to fourteen inches. Here again the principal rise and fall of the column coincided exactly with the inspiratory and

expiratory acts, the column being lowest during inspiration, and highest during expiration. Another proof that the inspiratory act draws the blood towards the chest is to be found in the fact that when a wound is made in a vein anywhere in the vicinity of the thorax, the air is most apt to enter during sighing, or when deep inspirations are made.

The late Dr. Buchanan, of Glasgow,[1] attaches great importance to respiration as an auxiliary of the circulation, and states his conviction that asphyxia is less due to the poisoning of the blood than to the fact that, when the breathing ceases, the heart is unable to carry on the circulation by itself.[2] I am not disposed to go thus far; for while admitting that respiration forms one of the forces of the circulation in the mammal, I cannot overlook the fact that in some of the lower animals the circulation is carried on where no respiration proper exists. The respiration may be divided into three kinds—namely, (*a*) the respiration due to the action of the chest and laryngeal muscles; (*b*) that due to the action of cilia, situated on the trachea and bronchial tubes; and (*c*) that occasioned by the diffusion of gases. The two former correspond to the visible vascular circulation; the latter to the invisible. The diffusion of gases in the lungs is analogous to the diffusion of fluids in the tissues. The chest and lungs form an apparatus for supplying fresh relays of air, just as the heart and blood-vessels form an apparatus for supplying fresh relays of blood. When once the air is inside the lungs it is made to pass in two directions, by the pulmonary cilia, and the tendency which the carbonic acid and the oxygen in the lungs have to diffuse or pass through each other. The ciliary movements produce currents within the air-passages and lungs akin to those produced within a bee-hive by the fanning of the wings of the bees at the entrance. The ciliary movements and passage of gases in opposite directions produce the primary circulation of air as it exists in the lowest animals; and it is not a little curious to find that, as the circulation of the blood becomes differentiated, so the breathing apparatus becomes complicated. Thus, to the ciliary movements and the mechanical diffusion of gases found in the lower animals, there is added in the higher a complex muscular and bony apparatus.

The movements of the chest, like those of the heart, are said to be active and passive; the expansion or opening of the chest and glottis being due, it is stated, to the contractions of the diaphragm, the intercostal muscles, and the crico-arytenoid muscles; the diminution or closing of the chest and glottis being due to the relaxation of these muscles, to the resiliency of the costal cartilages, and the elasticity of the pulmonic substance and vocal chords. Dalton states that the movement of expiration is entirely a *passive* one. I, on the other hand, regard the movement of expiration as well as that of inspiration as vito-mechanical. Dalton evidently experiences a difficulty in regarding expiration as a purely passive act; for he says, in expiration the muscles of both chest and glottis are relaxed, while the elasticity of the tissues, by a kind of *passive contraction* (observe, passive contraction), restores the parts to their original condition.[3] If contraction is active in inspiration, it must also be active in expiration, otherwise there is a contradiction in terms. It is worthy of remark that, according to current views, a vital act *opens* the chest, while it *closes* the ventricles of the heart. But why this discrepancy, seeing the movements of the thorax and ventricles are involuntary and rhythmic in character, and in this sense identical? There is plainly a difficulty here, which requires to be cleared up, and which only disappears when the opening and closing of the thorax and ventricles are regarded as vital in their nature. The presence of cartilage and bone in the thorax may be thought by some to afford a sufficient explanation, but these need not be taken into account, as the muscles of the thorax are arranged in such a manner as would enable them to open and close the chest even in the absence of the hard parts. Nor must it be forgotten that the movements of the thorax are muscular movements, and that whatever change is induced in the hard parts is referable to prior change in the soft parts.[4] If we attend to the inspiratory and expiratory movements in our own persons, and convert what are naturally involuntary movements into voluntary ones, we find that in inspiration we draw in the air by a vital act, and that in expiration we expel it by a vital act. This is proved by the fact that if we interfere either with inspiration or expiration, the movements are arrested. If we make a forcible inspiration, we must also, if we would avoid discomfort, make a forcible expiration.

§ 157. The Movements of the Mammalian Heart, interrupted and yet continuous. How the Heart rests.

Having described the direction and distribution of the muscular fibres composing the heart of the mammal, the order in which the several compartments of the heart act, and the change of shape induced in all muscles, whether

[1] "The Forces which carry on the Circulation of the Blood," by Andrew Buchanan, M.D., &c., Professor of Physiology, University of Glasgow.

[2] Professor Alison is of opinion that the effects of asphyxia first show themselves in the lungs, that the arterialisation of the blood has the power of attracting that fluid to the lungs, and of drawing it on through the capillaries, and that when this auxiliary to the circulation is cut off, the blood stagnates in the lungs. He assigns to the absorption and exhalation, which goes on in the lungs in a state of health, a power similar to that claimed by most physiologists for the tissues.

[3] Dalton's "Treatise on Human Physiology," p. 206.

[4] Since the above was originally written, Dr. Arthur Ransome has assigned an outward, forward, or pushing movement to the chest in inspiration; and an inward, backward, or pulling movement in expiration. These movements are seen to most advantage in women and children, where the ribs and costal cartilages are softest. (*Proceedings of the Royal Society*, November 21, 1872.)

voluntary or involuntary, in a state of activity, we are now in a position to speak of the general and particular movements of the heart. The following are the appearances observed in the living heart of a puppy one day old. The large veins at the base of the heart close in the direction of the auricles, and the auricles slowly open. The auricles then close in the direction of the ventricles with a vermicular wavy movement, somewhat suddenly, the ventricles opening meanwhile. Finally, the ventricles close suddenly and with great energy, a wave movement travelling in spiral lines from the apex to the base, and then from the base in the direction of the apex. When the heart is in motion it rotates on its long axis alternately to right and left, the extent of the rotation being rather more than a quarter of a turn either way. When the ventricles open, the left apex is elongated and pushed downward by a peculiar screwing motion, similar to that witnessed when a screw is being forced into wood. When the ventricles close, the left apex is shortened and elevated by a reverse screwing motion. The left apex, while this screwing motion is taking place, describes an irregular ellipse ; the apex impinging against the thorax, particularly towards the termination of the systole, when it gives a sudden bound in an upward and forward direction as if from recoil.[1] The movements performed by the left apex correspond with the impulse of the heart, and are largely due to the shape of the heart and to the fact that it is attached only at its base, the apex being at liberty to move with much greater freedom. The auricles close simultaneously, and so do the ventricles ; the auricles always opening when the ventricles close, and *vice versâ*. These structures increase and diminish by about a third when they open and close. They also change colour slightly. This is due to a diminution or increase in the quantity of blood in the walls of the heart and within its cavities, especially the cavities of the auricles, at any given time. It is trifling when compared with that observed in the heart of the frog or fish. The ventricles of the bird and mammal completely empty themselves during the systole. Of this there can be no doubt, as the ventricles are occasionally found so firmly closed after death that their internal or endocardial surfaces are in contact throughout. Analogy also favours this view. The ventricle of the fish and frog completely empties itself of blood and becomes pale during the systole. When the heart is beating normally, one or other part of it is always moving. When the veins cease to close and the auricles to open, the auricles begin to close and the ventricles to open, and so on in endless succession. In order to admit of these changes, the auriculo-ventricular valves, as has been stated, rise and fall like the diaphragm in respiration ; the valves protruding at one time into the auricular cavities and at another into the ventricular ones. There is in reality no pause in the heart's action. The one movement glides into the other as a snake glides into grass. All that the eye can detect is a quickening of the gliding movements at stated and very short intervals. A careful examination of the sounds of the heart shows that the sounds, like the movements, glide into each other. There is no actual cessation of sound when the heart is in action. There are periods when the sounds are very faint, and when only a sharp or an educated ear can detect them, and there are other periods when the sounds are so distinct that even a dull person must hear : but the sounds—and this is the point to be attended to—merge into each other by slow or sudden transitions. It would be more accurate, when speaking of the movements and sounds of the heart, to say they are only faintly indicated at one time, and strongly emphasised at another, but that neither ever altogether ceases.

If, however, the heart is acting more or less vigorously as a whole, the question which naturally presents itself is, How is the heart rested ? There can be little doubt it rests as it acts, namely, in parts. The centripetal and centrifugal wave movements pass through the sarcous elements of the different portions of the heart very much as the wind passes through leaves : its particles are stirred in rapid succession, but never at exactly the same instant ; the heart is moving as a whole, but its particles are only moving at regular and stated intervals ; the periods of repose, there is every reason to believe, greatly exceeding the periods of activity. The nourishment, life, and movements of the heart are in this sense synonymous. That the different parts of the heart act consecutively and in regular order was proved by Mr. Malden. He found that if a part of the ventricle of a frog or turtle was irritated exteriorly, it instantly contracted, the contraction spreading from the irritated point in every direction. He found, moreover, that before the contractile wave had spread over the entire ventricle, the part originally irritated, and which contracted first, expanded or bulged out to form a sacculation ; thus showing that the act of dilatation is as much a vital movement as the act of contraction. In proof of this, some poisons apparently kill the heart by destroying its expanding power, the organ in such cases being found firmly contracted after death. The older observers, as Pechlin, Perrault, Hamberger, and later on Bichat and Dumas, expressed their belief that the dilatation or expansion of the heart is a vital act in the same sense that its contraction is a vital act ; and it appears to me that modern physiologists have fallen into a grave error in stating that the contraction of the heart represents its only period of activity ; the heart being *passive* when it expands, or, as they term it, relaxes. The heart no doubt must rest like every other part of the body, and the most convenient explanation of the phenomenon is to suppose

[1] In the fish and frog the impulse of the heart, as has been explained, corresponds with the termination of the diastole and the beginning of the systole.

that when the heart is contracting and forcing out the blood it is active, but that when it is receiving the blood it is passive—that is, resting. This, however, as I have endeavoured to show, is not the real explanation, the heart performing work not only when it closes, but also when it opens. The heart cannot be said to be resting when it is returning to its position of rest, for if the sarcous elements are doing work from the time they leave their position of rest, it is obvious that they must be doing work until they return to it. The position of rest, moreover, of the ventricular walls does not correspond to that assumed by them during their diastole or opening, any more than to that assumed by them during their systole or closing. It corresponds to a line midway between both, as shown at x of Fig. 200, p. 543. In like manner the position of rest of the voluntary muscles is semi-flexion or semi-extension; the muscles being in a state of activity in complete flexion and complete extension. During repose the limbs are always slightly bent.

§ 158. Size of the Cavities of the Heart (Mammal).

The auricles and ventricles increase in all their diameters when they open, and decrease when they close. As, however, the auricles are always closing when the ventricles are opening, and the contrary, the actual contents of the pericardium fluctuate very little. This circumstance renders it somewhat difficult to determine whether the long diameter of the heart as a whole varies. This was a question keenly debated by the Montpellier and Parisian anatomists and physiologists, but is practically of little importance. There are several subjects which hinge on the degree of opening and closing which occurs in the heart. One of these is the comparative size of the auricular and ventricular cavities. Winslow, Senac, Haller, and Lieutaud maintain that the disparity in the size of the auricles and ventricles is considerable; Laennec, Bouillaud, Meckel, and Portal, that it is trifling; Lower, Sabatier, and Andral, that there is no difference whatever. The latter is most probably the correct opinion, as it is natural to suppose that the auricles contain the exact quantity of blood to be injected into the ventricles; these forcing out into the large arteries (aorta and pulmonary artery) a corresponding amount, which in due time is returned to the auricles by the large veins (venæ cavæ and pulmonary veins). This opinion is in a great measure corroborated by the practically incompressible nature of the blood. If a certain quantity of blood is forced out of one chamber, it is natural to suppose (seeing fluids are virtually incompressible) that a chamber of exactly the same size is prepared to receive it. A contrary supposition would tend to disturb the even tenor of the circulation. It is quite impossible, as I know from experience, to determine the size of the cavities of the heart after death, and there is no means of accurately ascertaining it during life. The parietes of the heart after death yield to such an extent that they may be distended at pleasure; a uniform pressure giving anything but a uniform expansion, as the ventricular walls, because of their varying thickness, become unequally stretched.

§ 159. Impulse of the Heart (Mammal).

Another subject arising out of the degree of opening and closing occurring in the living heart is the impulse or beat of the organ against the anterior wall of the chest. Is this due to the closing or opening of the heart? The heart during the diastole has its apex pushed deeper into the chest; and if to this circumstance be added the fact that at this particular period the organ is enlarged, we *à priori* arrive at the conclusion that the heart is impelled against the thorax during the diastole of the ventricles. Pigeaux, Burdach, and Beau entertained this belief. There can be no doubt, however, that the impulse in the mammal is communicated, not during the diastole of the ventricles, but during the systole. The illustrious Harvey found it so in man when the heart was exposed by disease. I have not had an opportunity of examining the human heart thus disclosed, but I have made observations on an anæsthetised living monkey, in which the pericardium was opened sufficiently to enable me to witness without disturbing the cardiac movements. The heart in this case beat with great regularity and apparently quite normally. The heart, when it opened and closed, rotated on its long axis in opposite directions, to the extent of nearly a quarter of a turn either way. The ventricles elongated themselves during the diastole, and shortened themselves during the systole; a spiral wave of motion travelling from the apex towards the base, and from the base towards the apex. The left apex had a distinct screwing motion. The left apex and the middle third of the right ventricle impinged against the thorax during the systole: the former structure describing an ellipse, as in the fish and frog. Senac stated correctly enough that the impulse is communicated during the systole, and endeavoured to prove his position by averring that the heart is suspended from two curved tubes, namely, the pulmonary artery and aorta; these tubes, when the blood is forced through them by the closing of the ventricles, endeavouring to straighten themselves, and causing the apex of the heart to impinge against the thorax. This is the principle on which the steam-gauges at present employed for registering steam-pressure are constructed. The

explanation is ingenious, but the large vessels, as Shebeare and Corrigan have shown, curve in such a manner that their recoil would not force the apex of the heart in the direction indicated, but just the opposite. There is this further objection, the ventricles are shortened in their long diameter during the systole. Senac seems to have been aware of this difficulty, for he endeavoured to strengthen his position by adding that the impulse was partly due to the expansion of the left auricle, which, because of its situation between the spine and the left ventricle, tended to force the apex of the heart outwards. The heart, however, tilts forwards when the large vessels are cut through, and it is altogether removed from the body; in which case, of course, neither the straightening of the vessels nor the swelling of the blood within the left auricle could produce any effect. The true explanation is, I believe, to be found in the shape of the ventricles, and in the distribution and direction of their muscular fibres. The ventricles form a twisted cone, which is flattened posteriorly and truncated obliquely in this direction at its base. The anterior fibres of the ventricles are consequently much longer than the posterior fibres; and as muscular fibres shorten in proportion to their length, this accounts for the heart tilting when removed from the body—the apex, as stated, describing a more or less perfect ellipse. A similar explanation was suggested by Professor Alison, and accepted by Mr. Carlisle and Dr. John Reid.

THE VALVES OF THE VASCULAR SYSTEM, ESPECIALLY IN MAN

The valves of the arteries, veins, and lymphatics in the vertebrates and man form part of that wonderful mechanism which consists of the heart, arteries, veins, capillaries, and lymphatics, and which has for its object the propulsion of the nutritive fluids in particular directions, with a view to nourishing and depurating the tissues and aërating the blood. The mechanism in question reveals what may be regarded as a system of irrigation and sewage which for complexity, completeness, and beauty is without parallel in the history of the world.

In all known systems of irrigation and sewage, rigid, closed, or open canals with or without sluices are employed —the number of sluices and subsidiary or small canals being comparatively few in number. In the higher animals, living, elastic, fluid-tight vessels, a large number of valves, and an infinity of small permeable vessels (capillaries) take their place.

The circulation calls to its aid the vital, and a large number of the physical forces, and employs a living central force-pump for propelling the blood long distances through the arteries and veins with impermeable walls, while it employs the forces of osmose, capillarity, cohesion, attraction, &c., to assist its passage through the capillaries with permeable walls. Here there is a remarkable blending of vital and physical forces for a common purpose; the living heart being aided in the work by certain non-living mechanical arrangements. The reader will form a graphic and, on the whole, not unfaithful picture of the mechanism of the circulation if he regards the heart, as indicated, as a great central force-pump, and likens the arterial and venous systems of blood-vessels and capillaries to twin trees which grow side by side, and whose branches, twigs, and leaves, even to the most minute, interweave and interdigitate in every direction; the blood, as it were, flowing from the root along the stem, branches, twigs, and leaves of the one tree, to the leaves, twigs, branches, and stem of the other tree to its root—the roots corresponding to the heart or point of departure.

He will add to the completeness of his picture by regarding the circulation as a carefully equilibrated fluid system; the blood in the arteries being balanced by the blood in the veins, especially in the lower extremities, where the valves are of the utmost consequence in supporting the vertical columns of blood, and if diseased or broken down, give rise to tortuous veins known as varicose; the blood zigzagging back to the right side of the heart and supporting itself in the bends of the diseased vessels. The valves are cunningly devised and exquisitely constructed, and so placed that they absolutely prevent a reflex or aberrant movement of the blood propelled by the heart, muscles, and accessory structures.

The valves present an infinite variety, and are miracles of design, combining as they do great strength, lightness, and adaptability. In some cases they act mechanically; in others vito-mechanically; in others vitally. On some occasions they are placed within virtually rigid tubes, in others in elastic yielding tubes, and in a third in actively closing and opening vessels and orifices. The segments composing the valves are, as a rule, semi-lunar and triangular in shape, and are, in some cases, furnished with tendinous cords (*chordæ tendineæ*) which regulate their movements and prevent their eversion. When tendinous cords are present they are attached to the bodies and margins of the segments and to finger-like muscular columns (*musculi papillares*), which shorten and elongate at intervals and adapt themselves perfectly to the work they have to perform. The segments of the valves vary, as a rule, from one to three, but they may greatly exceed that number, and are so constructed and placed that they project towards the centre of the vessel or opening to be closed. They are, in many cases, provided with pouches

(sinuses of Valsalva) behind them, the weight of the blood in which tends to close them. Their free margins, when the vessels are full of blood, meet or nearly meet each other in the centre of the vessel, so that the slightest reflux of the blood instantly closes them and the valve of which they form a part. The segments are closed in some cases by the mere apposition of their thin, delicate free margins. More commonly, and as I pointed out as far back as 1864,[1] they are closed by beautiful spiral wedging movements. The segments are, for the most part, composed of reduplications of the lining membrane of the vessels and endocardium of the heart, and these reduplications are strengthened in every direction by fibrous and elastic bands running vertically, longitudinally, and obliquely, and which cross each other after the manner of stays and struts, and produce enormously strong structures with comparatively little material. They are fashioned on the same type as the ventricles of the heart, and their extraordinary strength is none too great, seeing they have to perform duty day and night as long as life lasts. The segments of the mitral and tricuspid valves display the highest conceivable engineering skill. They are exquisitely graduated structures, thickest at the base and middle, and tapering towards the apex and free margins, where they are as thin as tissue paper. Every part of each segment is strengthened and supported by strong, branching, tendinous cords (*chordæ tendineæ*), so that rupture of their substance is practically an impossibility.

Occasionally the valves contain muscular fibres, and, in the right ventricle of the heart of the bird a wholly muscular valve takes the place of the fibro-membranous tricuspid valve in the mammal.

The complicated structure of the heart, vessels, and valves, and the mechanism of the circulation generally, can only be regarded as the work of a First Cause and of transcendent design. The circulation, regarded as a chance product, is utterly and absolutely unthinkable. The machinery of the circulation (visible and invisible) reveals mechanics and physics at their best, and that machinery grows in advance of the nutritive fluids it is created to transmit for longer or shorter distances. The machinery in question is created for an obvious purpose. Force-pumps and tubes—living and dead—cannot create or form themselves; neither can the former set themselves in motion and keep moving and sucking up and ejecting fluids in a constant continuous stream for practically unlimited periods. To perform this feat the engineer and artisan must lend a hand and exercise constant supervision. Similarly, the living heart with its concomitant blood-vessels and valves must be constructed, vivified, and set in motion and kept going by something outside of itself, and that something is unquestionably the First Cause itself.

The circulatory apparatus is composed not of one designed piece of mechanism, but of many, and each piece is perfectly adapted to, and works in harmony with, every other piece; further, the mechanism is self-moving, self-regulating, and self-fed. It works without ceasing from the time the child is born until it draws its last breath—it may be a period of one hundred or more years. What similar apparatus could be produced even by the most gifted designer and constructor which would go for a tithe of that time unattended and unaided?

The valves are important and interesting from a medical point of view, from the fact that they are occasionally the seat of morbid lesions which inaugurate a long list of painful complaints, very bewildering to the physician, and especially dangerous to the patient. In order fully to comprehend the nature and uses of the highly elaborated cardiac valves as they exist in man, a knowledge of the relations, structure, and functions of the more rudimentary valves found in the veins of mammals and in the hearts of the lower animals is necessary.[2]

§ 160. The Venous Valves—their Structure, &c.

The valves of the veins vary as regards the number of the segments composing them. In the smallest veins, and where small veins enter larger ones, one segment only is present. In the middle-sized veins of the extremities two segments are usually met with; while in the larger veins, as the internal jugulars of the horse, three and even four segments are by no means uncommon (Fig. 201, A–J, p. 550).

The segments, whatever their number, are, as indicated, semilunar in shape (Fig. 201, A, B, C, H), the convex borders being attached to the wall of the vessel; the crescentic or concave margins, which are free and directed towards the heart, projecting into it. When a valve is composed of one segment, the segment is placed obliquely in the vessel, its attached convex border occupying rather more than a half of the interior. When the segment occurs at the junction of a smaller with a larger vein (Fig. 201, H), its convex border (*a*) is attached to a half or more of the orifice of the smaller one where it joins the larger, its free margin (*b*) running transversely to the larger trunk. In such cases the segment acts as a movable partition or septum, common alike to both vessels; but its position

[1] "On the Relations, Structure, and Function of the Valves of the Vascular System in Vertebrata." (*Transactions of the Royal Society of Edinburgh*, 1864.)

[2] *Vide* Memoir "On the Valves of the Vascular System in Vertebrata," by the Author. (*Transactions of the Royal Society of Edinburgh*, vol. xxiii. Part III., 1864.) The preparations on which this investigation is based are preserved in the Hunterian Museum of the Royal College of Surgeons of England, London.

and relations are such, that while it readily permits the blood from the smaller vein to enter the larger one, it effectually prevents its reflux or return.

When the valve consists of two segments they are semi-lunar in shape, and very ample, the vertical measurement of each being not unfrequently nearly twice that of the diameter of the vessel. In such cases both segments are usually of the same size, so that they divide the vessel into two equal parts (Fig. 201, B, C, F). They are placed across the vessel, their free margins being inclined towards the heart and the mesial plane of the vessel. The free margins, when the vessel is placed in fluid, run parallel with each other (Fig. 201, E, *e*; Fig. 202, E, *e*, p. 551). The attached margins, on the other hand, diverge to form festoons in the interior of the vessel (Fig. 201, A, *r*, *s*, *t*). This is necessary, as the attached margins must accommodate themselves to the interior of the vessel, which is more or less circular. The free margins of the segments, like the attached ones, start from a common point (Fig. 201, C, *r*); but the shape of the segments, and the angle at which they are placed with regard to each other and the mesial plane of the vessel, are such that the free margins do not diverge to the same extent as the attached ones, but run in a nearly straight line across the vessel. I was much struck, on injecting, with fluid, coloured plaster of Paris, the external saphenous vein of the human subject from the dorsum of the foot, to find, on dissection, that the free margins of the segments of some of the valves were in contact throughout; clearly showing that when the segments are allowed to float in a fluid, they are more or less parallel, and so projected towards each other that even the slightest reflux instantly closes them. This relation of the segments is in part accounted for by the presence of a fibrous structure (Fig. 201, C, *r*), which extends from the wall of the vessel into the interior, and supports them at a certain distance from the sides of the vessel. The fibrous structure referred to is well seen in the semilunar valves of the pulmonary artery and aorta (Fig. 203, A, *b*, p. 553), and seems to have hitherto escaped observation. In a line corresponding to the attached border of each of the segments, the middle and internal coats of the vein are thickened, as may be ascertained by a vertical section, or by introducing coloured plaster of Paris into the vessel.[1] I particularly direct attention to this circumstance, as the thickenings referred to form fibrous zones which extend for a short distance into the substance of the segments, and afford them a considerable degree of support (Fig. 201, E, *h*; C, *r*). They further assist in preserving the shape of the segments, and in enabling them to maintain the proper angle of inclination; the said angle inclining the segments towards each other in the mesial plane of the vessel (Fig. 201, E, *e*). When a valve consisting of two segments is situated at the junction of a smaller with a larger vein, one of the segments is usually placed between the two vessels at the point of juncture (Fig. 201, J, upper *b*), the other on the wall of the smaller vein (upper *a*). The position of the segments in such instances varies, their long diameter sometimes running parallel with the larger vessel, sometimes obliquely, but more commonly transversely. When the valve consists of three segments (Fig. 201, A and G), the segments, as a rule, are unequal in size, one of them being generally a little larger (*t*) than either of the other two (*r*, *s*). They are semilunar in shape, as in the smaller and middle-sized veins, and differ from the latter in being less capacious. The tri-semilunar valves in the veins may therefore be regarded as intermediate between the fully-developed bi-semilunar valves found in the veins of the extremities and the fully-developed tri-semilunar valves which occur at the origins of the pulmonary artery and aorta. The existence of valves in the veins is indicated externally by a dilatation or enlargement of

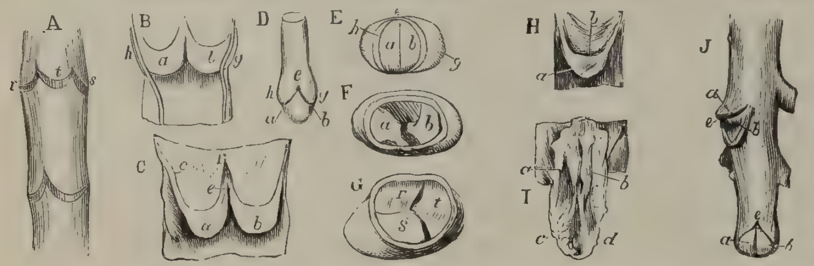


FIG. 201.—A. External jugular vein of horse inverted. Shows valve, consisting of three (*r*, *s*, *t*) segments (the Author, 1864).
B. Section of external jugular vein of horse. Shows valve consisting of two segments (*a*, *b*), with dilatations (*g*, *h*) corresponding to the sinuses of Valsalva in the arteries (the Author, 1864).
C. External jugular vein of horse opened, to show the relations of the segments (*a*, *b*) where they come together (*e*), and are united by fibrous tissue (*r*). The free margin of one of the segments is seen at *c*, the attached margin at *a* (the Author, 1864).
D. Portion of femoral vein distended with plaster of Paris. Shows dilatations (*h*, *g*) in the vessel behind the valve; *a*, *b*, segments of valve; *e*, point where the segments come together when the valve is acting (the Author, 1864).
E. Shows venous valve, consisting of two segments (*a*, *b*) in action; *h*, *g*, bulgings corresponding to sinuses of Valsalva; *e*, line formed by the margins of the segments flattening against each other (the Author, 1864).
F. The same, not in action.
G. Venous valve from external jugular of horse, consisting of three segments (*r*, *s*, *t*) (the Author, 1864).
H. Venous valve of one segment situated at the confluence of a small with a large vein. *a*, Attached convex border; *b*, free crescentic border (the Author, 1864).
I. Venous sinus from the auricle of a sturgeon. *a*, *b*, Muscular walls of sinus; *c*, *d*, muscular fasciculi which assist in opening and closing the sinus (the Author, 1864).
J. Femoral vein distended with plaster of Paris. Shows two sets of venous valves in action; the one set (upper *a*, *b*) where a small vein enters a larger one; the other (lower *a*, *b*) in the principal vessel; *e*, line of junction between the segments of the venous valves. The segments are flattened when they come in contact, so that, if forcibly separated, they display a smooth crescentic surface, represented at E, *e* of Fig. 202 (the Author, 1864).

[1] I have derived much information from the employment of this material; its use having enabled me to determine with accuracy the relation of the segments of the valves to each other when in action, and other points connected with the physiology of the heart.

the vessel (Fig. 201, D, *h*, *g*, p. 550; Fig. 202, A, *h*, *g*), the dilatation consisting of one, two, or three swellings, according as the valve is composed of one, two, or three segments. These dilatations or swellings are analogous to the sinuses of Valsalva in the arteries (Fig. 203, A, B, *d*, p. 553). They form, with the segments to which they belong, open sinuses or pouches which look towards the heart, and as they extend nearly as far in an outward direction as the segments project inwardly, they give a very good idea of the size and shape of the segments themselves. The object of the swellings is evidently twofold—firstly, to cause the blood to act on the segments of the valve from without inwards—that is, in the direction of the mesial plane, or of the axis of the vessel, according as there are two or three segments present; and secondly, to increase the area over which the pressure exerted by the reflux of the blood extends.

The segments of the venous valves are exceedingly flexible, and so delicate as to be semi-transparent. They possess great strength and a considerable degree of elasticity.[1] Usually they are described as consisting of a reduplication of the fine membrane lining the vessel, strengthened by some included fibro-cellular tissue, the whole being covered with epithelium. This description, however, is much too general to convey an accurate impression of their real structure, and the following, taken from my notes of a large number of dissections, including man, the horse, ox, sheep, and other animals, may prove useful.

When one of the segments of a well-formed bi-semilunar valve removed from the human femoral vein is stained with carmine, fixed between two object glasses, and examined microscopically, I find the following :—

1st. The lining membrane of the vessel which forms the investing sheath of the segment, and which is covered with epithelium.

2nd. Large quantities of white fibrous tissue mixed up with areolar and yellow elastic tissue, and a certain amount of non-striped muscular fibres from the middle coats of the vessel. The distribution of the fibres is represented at B, C, D of Fig. 202.

FIG. 202.—Vertical section of vein distended with plaster of Paris. Shows the nature of the union between the segments (*e*). *h*, *g*, Pouches behind the segments (*a*, *b*) (the Author, 1864).
E. The same, the section being carried between *e*, instead of across or through the segments. *e*, Portion of segment flattened against corresponding segment, which in this case is removed; *b*, portion of segment not flattened by pressure; *g*, bulging of wall of vein behind segment (the Author, 1864).
B, C, D. Show the structure of the venous valves (the Author, 1864).

Thus running along the concave or free margin of the segment (Fig. 202, B, *a*), as likewise on the body, specially where the segments join each other (*b*), is a series of very delicate fibres, consisting principally of yellow elastic tissue. These fibres proceed in the direction of the long diameter of the segment, but transversely to the course of the vessel, and may be denominated the horizontal fibres.

Running in a precisely opposite direction, and confining themselves principally to the body of the segment, is a series of equally delicate fibres (*c*), having a like composition, which, for the sake of distinction, may be described as the vertical series. These two sets of fibres are superficial, and to be seen properly a power magnifying from 200 to 250 diameters is required.

Radiating from the centre of the segment (Fig. 202, C, *e*), towards its attached border (*i*, *j*), and seen through the more delicate horizontal and vertical ones, is a series of stronger and deeper fibres, composed of white fibrous and yellow elastic tissue, the former predominating. Still stronger and deeper than either of the fibres described, and proceeding from the attached border of the segment (Fig. 202, D, *s*, *t*), is a series of oblique fibres, continuous in many instances, with corresponding fibres in the middle coat of the vessel. These fibres cross each other with great regularity, and form the principal portion of the segments. They are most strongly marked at the margin of the convex border of the segment, where they form a fibrous zone or ring, which, as has been explained, supports the segment, and carries it away from the sides of the vessel into the interior. I have also detected, in the vicinity of the attached border of the segment, some non-striped muscular fibres. The segment of a venous valve, it will be observed, is a highly symmetrical and complex structure, the fibrous tissues composing it being arranged in at least three well-marked directions; namely, horizontally, vertically, and obliquely. The great strength which such an arrangement is calculated to impart to the segment is readily understood.

The segment is thinnest at its free margin, and thickest towards its attached border. This follows because the free margins of the segments support each other when the valve is in action—the strain falling more upon the attached borders.

[1] Hunter denies the elasticity of the segments, on the ground that the valvular membrane is not formed of a reduplication of the lining membrane of the vessel—an opinion at variance with recent investigation. ("Treatise on the Blood," pp. 181, 182.)

§ 161. The Venous Valves in Action.

The manner in which the venous valves act is well seen when a vein is suspended perpendicularly overhead, and water, oil, glycerine, or liquid plaster of Paris poured into it by an assistant from above. In order to witness this experiment properly, that part of the vein beneath the valve should be cut away, the better to expose the segments to the view of the spectator. When the valve consists of one segment only, the fluid is observed *to force it obliquely across the vessel,* and to apply its free crescentic margin to the interior or concave surface of the vessel with such accuracy as to prevent even the slightest reflux. When two segments occur in the course of a vein *they are forced by the fluid simultaneously towards each other in the mesial plane of the vessel* (Fig. 201, E, *e ;* J, *e*, p. 550), the sinuses behind the segments becoming distended, and directing the current and regulating to a certain extent the amount of pressure. The closure in this instance is almost instantaneous, and so perfect that not a single drop escapes. It is effected by *the free margins of the segments, and a large portion of the sides of the segments,* coming into accurate contact, the amount of contact increasing in a direct ratio to the pressure applied. If liquid plaster of Paris is employed for distending the vein, and the specimen is examined after the plaster has set, one is struck with the great precision with which the segments act (Fig. 201, E, *a, b ;* J, *a, b ;* Fig. 202, A, *a, b*); these coming together so symmetrically that they form by their union *a perpendicular wall or septum* (Fig. 202, A, *e*) *of a beautifully crescentic shape* [1] (E, *e*). This fact is significant, as it clearly proves that the free margins of the segments and a considerable proportion of the sides are pressed against each other when the valve is in action, a circumstance difficult to comprehend, when it is remembered that the attached borders are applied obliquely to the walls of the vessel, and that the segments, when not in action, incline towards each other at a considerable angle. When three segments are present, as happens in the larger venous trunks, the closure is effected as in the semilunar valves of the pulmonary artery and aorta. The fluid employed, in virtue of the direction given to it by the venous sinuses, causes each of the segments (Fig. 201, G, *r, s, t*, p. 550) to fold or double upon itself at an angle of something like 120° ; the three lines formed by the folding and union of the three segments dividing the circle corresponding to the wall of the vessel into three nearly equal parts (compare with Fig. 166, p. 499). In the folding of the segments upon themselves, each segment regulates the amount of folding which takes place in that next to it, and as the free margins of the segments so folded advance synchronously towards the axis of the vessel, they mutually act upon and support each other. As the three segments are attached obliquely to the wall of the vessel, while the free margins, after the folding has taken place, are inclined towards and run parallel with each other, they form a dome, the convexity of which is always inclined towards the heart. The dome consists of three nearly equal parts, the margins of the segments, and a certain portion of the sides, when the pressure of the refluent blood is applied, flattening themselves against each other to form three crescentic partitions or septa,[2] which run from the axis of the vessel towards the circumference (compare with *r, s, t ; v, w, x*, of Fig. 204, p. 554).

The tri-semilunar valve, as will be seen from the foregoing description, is closed in a somewhat different manner from the bi-semilunar one. The occlusion of the vessel, however, is not the less complete ; the segments, when three are present, *being spirally wedged into each other from without inwards and away from the heart.* This spiral movement, which has not been referred to by any previous investigator, is simply indicated in the venous valves, is more strongly marked in the semilunar ones of the pulmonary artery and aorta (Fig. 204, *r, s, t ; v, w, x*, p. 554), and attains, as will be shown subsequently, a maximum in the auriculo-ventricular valves of the mammal (Figs. 40–43, pp. 268, 281).

By whatever power the blood in the veins advances—whether impelled by the heart alone, or aided by the shortening and lengthening of muscles in different parts of the body, or by rhythmic movements which take place in the vessels themselves, or by respiratory efforts, or by atmospheric pressure, or by combinations of all of these —there can be no doubt that this fluid, in its backward or retrograde movement, acts mechanically on the valves as described. It ought, however, to be borne in mind that the veins and the valves are vital structures, and that, although a perfect closure may be effected by purely mechanical means in the dead vein, it is more than probable that, in the living one, the coats of the vessel, with their included nerves, exercise a regulating influence.

§ 162. The Arterial or Semilunar Valves—their Structure, &c.

The arterial valves may be regarded as occupying an intermediate position between the venous valves on the one hand, and the auriculo-ventricular valves on the other. The segments composing them are three in number,

[1] In order to see the perpendicular wall formed by the flattening of the sides of the segments against each other when the valve is in action, the vein and the plaster should be cut across above the valve, and the segments forcibly separated by introducing a thin knife between them. In Fig. 202, E, one of the segments has been so removed.

[2] The crescentic partitions, as they occur in the semilunar valves of the pulmonary artery and aorta, are shown at Fig. 203, C, *b*, p. 561.

and resemble the segments of the venous valves in their shape, position, mode of attachment, and movements; whereas structurally they are more nearly allied to the segments of the auriculo-ventricular, that is, the mitral and tricuspid, valves. Like the venous valves, the arterial occupy the interior of vessels, and are crescentic in shape. Thus the segments have a free, crescentic, thin margin, and a thicker convex, attached margin. The convex margin is firmly secured to the scalloped aortic and pulmonic fibrous rings (Plate lxxxv., Fig. 3, *g*, *h*, p. 325). The segments, as already pointed out, are surrounded by a fibrous framework, which enables them to maintain their shape and relative position to each other. This framework carries the segments away from the interior of the vessel, and inclines their free margins towards its axis, so that if the vessel, with its semilunar valve, be submerged, the free margins of the segments are naturally more or less in contact—an arrangement which insures the immediate closure of the valve the instant the blood regurgitates. The great vessels are thickened where the segments approach each other (Fig. 203, A, *b*), and thinned and dilated behind each segment (B, *i*), to form three large cavities or sinuses, known as the sinuses of Valsalva (B, *d*). These sinuses contain a considerable amount of residual blood, which by its weight and pressure assists in closing and wedging the segments together during the diastole. They are also the receptacles which receive the segments during the systole—an arrangement which increases the diameter of the great vessels at their origins at this particular period (Fig. 167, *e*, p. 499). When the reflux of the blood occurs, the segments of the semilunar valves fold or bend at their central portions in such a manner that their free margins, and the sides in the vicinity of the margins, become accurately applied to and flattened against each other; the flattening increasing according to the pressure. This arrangement effectually prevents regurgitation in healthy valves (Fig. 203, A, B, C, D).

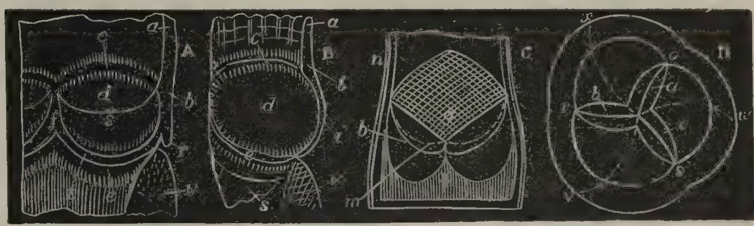


FIG. 203.—A. Section of pulmonary artery and right ventricle of human heart between the segments of the semilunar valve. Shows the variation in the thickness of the vessel (*a*, *b*) and how it bifurcates (*r*) at its origin. *s*, Segment of valve; *c*, *b*, *t*, *f*, fibrous framework surrounding it; *d*, sinus of Valsalva; *e*, pulmonic fibrous ring; *v*, ventricle (the Author, 1864).

B. Similar section carried through pulmonary artery (*a*, *b*) and middle of segment (*s*). Shows the thinning of the vessel in this situation (*i*). *c*, Portion of fibrous framework; *d*, sinus of Valsalva; *e*, pulmonic fibrous ring; *v*, ventricle (the Author, 1864).

C. Human semilunar valve distended with plaster of Paris, and one of the segments (*g*) removed to show the shape of the lunulæ or opposing surfaces which come together when fluid pressure is applied to the segments. *n*, Aorta; *m*, flattened portion of segment. This flattening increases with the pressure, as at *b*. The flattening represents the degree of contact between the segments. It is much greater than is usually supposed (the Author, 1864).

D. Shows how the segments of the semilunar valve are folded, flattened, and spirally wedged into each other when the valve is closed. *v*, *w*, *x*, Direction in which the blood flows down upon the segments to fold them; *o*, *r*, *s*, line of union between the segments; *c*, *a*, *b*, nature and amount of flattening occurring along the free margins of the segments (the Author, 1864).

The sinuses of Valsalva are not arranged in the same plane. They are, moreover, unequal in size. The highest and smallest is placed anteriorly, that which is intermediate in size posteriorly, the lowest and largest being directed towards the septum. They correspond in situation and dimensions to the segments behind which they are found, and differ from the venous sinuses in being more capacious, a section of the sinus and its segment (which is likewise very ample) giving a sweep of nearly half a circle. As a result of this amplitude, those portions of the segments which project into the vessel are, during the action of the valve, closely applied to each other throughout a considerable part of their extent (Fig. 203, C, *b*; D, *a*, *b*, *c*), the great size of the sinuses furnishing an increased quantity of blood for pressing the segments from above downwards, and from without inwards, or in the direction of the axis of the vessel. *The sinuses of Valsalva, it should be explained, curve towards each other in a spiral manner;* and this ought to be attended to in speaking of the action of the semilunar valves, as the sinuses direct the blood spirally on the mesial line of each segment (Fig. 203; D, *v*, *w*, *x*), and cause the segments to twist and wedge into each other, as shown at *r*, *s*, *t*, *v*, *w*, *x*, of Fig. 204. In order to determine this point, I procured a fresh pulmonary artery and aorta, and after putting the valves in position with water, caused an assistant to drop liquid plaster of Paris into the vessels. The greater density of the plaster gradually displaced the water, and I was in this way furnished with accurate casts of the sinuses and of the valves. The segments of the semilunar valves are unequal in size, and consist of a reduplication of the fine membrane lining the pulmonary artery and aorta, strengthened by certain tendinous bands, and, as was first satisfactorily demonstrated by the late Sir W. S. Savory, of a considerable quantity of yellow elastic tissue.[1] Some of the older anatomists, among whom may be mentioned Lancisi,[2] Senac,[3] Morgagni,[4] Winslow,[5] and Cooper,[6] believed that they had detected the presence of carneous or muscular fibres; but Haller,[7] and many since his time, have

[1] Purkinge and Räuschel had detected elastic tissue in the corpora Arantii, but knew nothing of its existence throughout the other portions of the valves. Of its presence I have frequently satisfied myself.

[2] De Motu Cordis.

[3] Traité de la Structure du Cœur. Livre i.

[4] Adversaria Anatomica Omnia.

[5] Exposition Anat. de la Structure du Corps Humain, p. 592.

[6] Myotomia Reformata.

[7] Elementa Physiologiæ. Liber iv. sect. 10.

gravely doubted the accuracy of their observations. Mr. Moore [1] has figured two sets of muscular fibres, which he has termed, according to their supposed action, dilators and retractors; and Dr. Monneret has described two similar sets, which, for like reasons, he has named elevators and depressors. I have sought in vain for the muscular fibres in question, and am inclined to think that, when supposed to have been found, they were really only the tendinous bands accidentally stained with blood. The tendinous bands have hitherto been regarded as following three principal directions—one band being said to occupy the free margin, and to be divided into two equal parts by the nodulus or corpus Arantii, otherwise called corpusculum Morgagni, and corpus sesamoideum; a second band, proceeding from points a little above the middle of the segment, and curving in an upward direction towards the corpus Arantii; the third band, which is the thickest, surrounding the attached border of the segment. A careful examination of a large number of mammalian hearts, particularly those of man, has induced me to assign to the semilunar valves a more intricate structure (Fig. 205, A—E).

In a healthy human semilunar valve taken from the pulmonary artery,[2] the following, so far as I can make out, is the arrangement. Proceeding from the attached extremities of the segment above, and running along its free

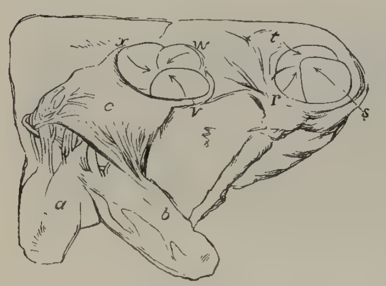


FIG. 204.

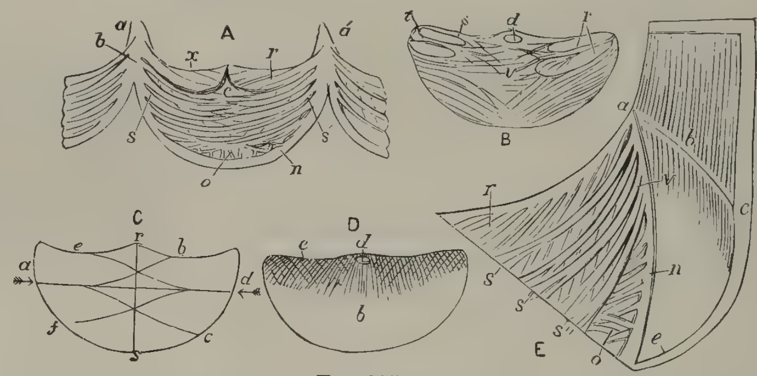


FIG. 205.

FIG. 204.—Base of heart, with right and left ventricles removed to show the pulmonic, aortic, and mitral valves. The pulmonic and aortic valves (*r, s, t; v, w, x*) have been closed by pouring liquid plaster of Paris into them. The mitral valve (*c*) is open, it always happening that when the semilunar valves are closed, the auriculo-ventricular ones are open. The segments of the pulmonic and aortic valves (*vide* arrows *r, s, t; v, w, x*) are spirally wedged into each other. *a, b,* Right and left musculi papillares of left ventricle; *c,* aortic segment of mitral valve. (Photograph of dissection of the Author, 1864.)

FIG. 205.—A. Segment of human semilunar valve (pulmonic) suspended from fibrous band (*a, a'*). *x, r,* Lunulæ which, when the valve is in action, become accurately applied to corresponding lunulæ in the two remaining segments; *c,* portion of segment usually thickened in old people. The thickening is absent in young, healthy valves. *n,* Thickened convex border attached to fibrous ring of pulmonary artery; *o,* thinner portion of segment; *s, s',* fibrous bands which split up in the mesial line of the segment, in order to support and strengthen it. These structures are better seen at E, which represents the terminal portion of the aorta of a whale with a half segment of one of the semilunar valves attached. *a, b, c,* Thickened portion of aorta; *e,* thinned portion; *a, n,* fibrous ring attaching segment of valve to aorta; *r,* free margin or delicate lunula of segment; *o,* thicker portion of segment; *v, s, s', s'',* thickest portion of segment, consisting of fibrous bands which break up into brush-shaped expansions, and at once strengthen and support the segment. A scheme of the arrangement of these bands is given at C. *r, s,* Mesial line of segment; *a,* band splitting up into *b* and *c*; *d,* band splitting up into *e* and *f*. At B a semilunar segment (*v*) is shown, where the bands which split up (*s, t*) are separated by a very delicate membrane (*r*), and so resemble chordæ tendineæ. This segment is abnormally thickened and presents a well-marked corpus Arantii (*d*). At D a segment (*b*) is shown with its free crescentic borders (*e*) thickened. This too presents a corpus Arantii (*d*). (Drawn from the dissections of the Author, in the Hunterian Museum of the Royal College of Surgeons of England, London, 1863–64.)

margin, is a delicate tendinous band which gives off still more delicate slips (Fig. 205, A, *x, r*) to radiate in a downward and inward direction—that is, in the direction of the mesial line and body of the segment. These fine slips split up and interdigitate in the mesial line, and are attached below to the uppermost of a series of very strong fibrous bands which occupy the body of the segment (*s, s'*). In the interspaces between the slips the valve is so thin as to be almost transparent. Those portions of the segments included within the delicate fibrous band, running along the free margin and the uppermost of the stronger bands occupying the body, are somewhat crescentic in shape (*r*), and have, from this circumstance, been termed lunulæ. They do not form the perfect crescents usually represented in books, the horns of the crescents directed towards the mesial line of the segment being much broader than those directed towards the extremities, or where the segments unite above. The object of this arrangement is obvious. The broader portions of the crescents are those which, when the segment is folded upon itself during the action of the valve, are accurately applied to corresponding and similar portions of the two remaining segments (Fig. 203, C, *b*; D, *a, b, c,* p. 553). If, however, the lunulæ had been symmetrical—in other words, if they had terminated in well-defined horns towards the mesial line, or where the segments fold upon themselves—then the union between the segments in the axis of the vessel (Fig. 203, D), where great strength is required, would have been partial and imperfect.

[1] *Med. Gazette,* March 8, 1850.

[2] It is comparatively a difficult matter to get a perfectly healthy human aortic semilunar valve, especially if the patient is at all advanced in years. Out of twenty adult hearts examined by me, nearly half of that number had the valves abnormally thickened.

Proceeding from the attached extremities of the segments at points a little below the origins of the marginal band, and curving in a downward and inward direction, is the first of the stronger bands (Fig. 205, A, *b*, p. 554). The band referred to splits up into brush-shaped expansions as it approaches the mesial line (*c*), where it interdigitates and becomes strongly embraced. Other and similar bands, to the extent usually of five (*s*), are met with, and as they all curve in a downward and inward direction, and have finer bands running between them in a nearly vertical direction, they suspend the body of the segment; so that when blood or water is directed upon it, the various parts of which it is composed radiate from the attached or convex border (*b*, *s*) like a fan, each band dragging upon that above it; the whole deriving support from the thickened convex margin. The bands are best seen on that aspect of the segments which is directed towards the sinuses of Valsalva. The surfaces of the segments directed towards the axis of the vessel are perfectly smooth, and so facilitate the onward flow of the blood. The bands are thickest at their attached extremities, where they interlace slightly, and are mixed up to a greater or less extent with the pale, soft, flattened fibres and elastic tissue of the central layer of the vessel. The several points alluded to are delineated in Fig. 205, E, p. 554.

As the bands under consideration are exceedingly strong when compared with those occurring in other portions of the segments, and project in an inward direction, or towards the axis of the vessel, when the preparation is sunk in water, their function, as ascertained from numerous experiments on the semilunar valves of a whale (*Physalus antiquorum*, Gray), seems to be the following:—

First, *They carry the bodies of the segments away from the sides of the vessel, and incline their free margins towards each other at such an angle as necessitates the free margins of neighbouring segments being always more or less in apposition.* In this they are assisted by the thickened portion of the pulmonary artery which projects between the segments, where they unite above, and by the fibrous zones which correspond to the convex border of each segment (Plate lxxxv., Fig. 5, p. 325).

Second, *The stronger fibres suspend the bodies of the segments from above, and permit the reflux of blood to act more immediately upon the mesial line of each segment where thinnest and where least supported,* to occasion that characteristic folding of the segments upon themselves when the valve is in action. The closure of the valve is in part due to the weight of the blood in the vessels and sinus of Valsalva, in part to the sucking action of the right ventricle when opening, and in part to the elastic properties of the artery.

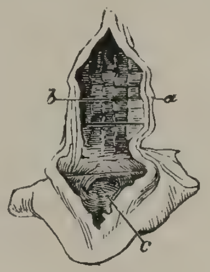


FIG. 206.

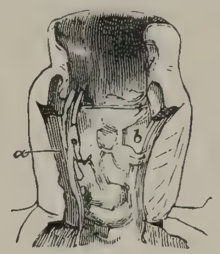


FIG. 207.

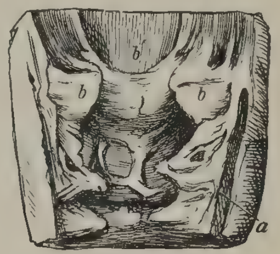


FIG. 208.

FIG. 206.—Bulbus arteriosus and ventricle of sturgeon; the former (*a*) displaying five rows of semilunar valves (*b*), the latter an auriculo-ventricular valve (*c*), with numerous tendinous bands running into it (the Author, 1864).

FIG. 207.—Bulbus arteriosus and portion of ventricle of lepidosteus. Shows the great thickness of the bulb (*a*), and of the valves (*b*), between which tendinous bands run (the Author, 1864).

FIG. 208.—Portion of bulbus arteriosus of basking shark. Shows the great thickness of the bulb (*a*) and of the valves (*b*), and how the latter support each other (the Author, 1864).

From the foregoing it will be perceived that the segments of a semilunar valve are bilaterally symmetrical, and constructed on a plan which secures the greatest amount of strength with the least possible material (Fig. 205, C, p. 554).

On some occasions the tendinous bands proceeding from the marginal one are abnormally thickened (Fig. 205, B, *s*, *t*), and terminate in brush-shaped expansions in the body of the segment (*v*); the body under such circumstances projecting in an upward direction towards the corpus Arantii (*d*). In such cases, those portions of the valve which occur between the thickened bands proceeding from the marginal one are exceedingly thin, and in some diseased conditions altogether absent (*r*), so that the segment very much resembles one of the segments of the mitral or tricuspid valve, with its chordæ tendineæ. That there is an analogy between the semilunar and the mitral and tricuspid valves, and that the tendinous chords are a further development, seems probable from the fact that in the bulbus arteriosus of certain fishes, as the gray and basking sharks, lepidosteus, &c., the semilunar valves are furnished with what may be regarded as rudimentary chordæ tendineæ (Figs. 207 and 208, *b*); the auriculo-ventricular valves of fishes, which have hitherto been regarded as semilunar, exhibiting tendinous chords in various stages of development (Fig. 206, *c*).

The corpus Arantii is never present in a perfectly healthy semilunar segment; nor will its absence occasion surprise, when it is stated that its presence materially interferes with the folding and accurate apposition of the segments upon themselves when the valve is in action. That its existence is not necessary to the perfect closure of a semilunar valve, is proved by its complete absence in the segments of the human pulmonic valve, in the segments of the pulmonic and aortic semilunar valves of the lower animals, and in all veins. In the semilunar valve of the

whale, where one would have naturally expected the corpus Arantii in perfection, I could not detect even a trace of it. I am therefore disposed to regard it as a morbid condition, due to disease, thickening, and deposit.

What has been said of the semilunar valves of the pulmonary artery may with equal propriety be said of those of the aorta; the only difference being that the segments of the aorta are stronger and more opaque, to harmonise with the greater strength of the left ventricle.

§ 163. The Arterial or Semilunar Valves in Action.

As the manner in which the semilunar valves are closed does not seem to be well understood, an account of some experiments conducted by me, so far back as 1864,[1] with various fluids and liquid plaster of Paris may prove interesting:—

When the aorta is cut across an inch or so above the aortic semilunar valve, and water introduced, the segments, if watched from beneath, are seen to act with great alacrity, the smallest segment, which is situated highest, descending with a spiral swoop, and first falling into position; the middle-sized segment, which is placed a little lower, descending in like manner, and fixing the first segment by one of its lunulæ or crescentic surfaces; the third and largest segment, which occupies a lower position than either of the others, descending spirally upon the crescentic margins of the other two, and wedging and screwing them more and more tightly into each other. The spiral movement, as has been already explained, is occasioned by the direction of the sinuses of Valsalva, which curve towards each other, and direct the blood in spiral waves upon the mesial line of each segment (Fig. 203, D, *v*, *w*, *x*, p. 553; Fig. 204, *v*, *w*, *x*, p. 554).

From the foregoing description of the venous and arterial semilunar valves in mammalia, it will be evident that there is nothing either in their structure or relations to betoken any great degree of activity on their part. That these structures are, on the contrary, to a great extent passive, seems certain from the fact that a stream of water or other fluid directed upon them from above as recommended at once closes the orifices which they guard. Thus far my descriptions have been confined to the so-called venous and arterial semilunar valves of the mammal. I will now deal with similar structures in the fish, reptile, and bird.

§ 164. Semilunar and other Valves of the Fish, Reptile, and Bird.

The semilunar valves in the bulbus arteriosus of the fish, and the auriculo-ventricular valves in the fish and reptile, differ from the venous and arterial semilunar valves of the mammal in being, for the most part, exposed, either directly or indirectly, to the influence of muscular movements. The bulbus arteriosus is a muscular structure which opens and closes like the other parts of the heart. As a consequence, the valves situated in its interior are opened and closed by vito-mechanical movements. The segments vary as regards number, size, and shape, apparently with a view to meeting the requirements of the structure in which they occur. Thus, in the frog-fish (*Lophius piscatorius*), the origin of the bulbus arteriosus is guarded by a semilunar valve, consisting of two ample and very delicate segments, resembling those found in the middle-sized veins; while in the sun-fish (*Orthagoriscus mola*, Schneider) the same aperture is guarded by a semilunar valve consisting of three segments, the segments being analogous in every respect to those found in the largest veins, and in the pulmonary artery and aorta. As the valve in these cases is situated between the actively moving bulbus arteriosus and ventricle, it is surrounded by a fibrous ring similar to that occurring at the origin of the pulmonary artery and aorta in man. The movements of the valve are consequently not affected by the movements of the bulbus arteriosus and ventricle to any great extent. The semilunar valves in the frog-fish and sun-fish are to be regarded as connecting links between the venous and arterial ones in the bird and mammal, and that more complex system of analogous valves which is found in the bulbus arteriosus of fishes generally. In the bulbus arteriosus of the skate (*Raia batis*), the segments occupy the whole of the interior of the bulb, and are arranged in three pyramidal rows of five each. As the segments in this instance are very small, and cannot obliterate the cavity of the arterial bulb, they must be looked upon as being useful only in supporting the column of blood; it being reserved for the segments at the termination of the bulb, which are larger and more fully developed, to effect a closure. The action of the segments in the bulbus arteriosus of the skate is rendered more perfect by the pressure from without, caused by the closure of the bulb itself. In the bulbus arteriosus of the sturgeon (*Accipenser sturio*), the segments are arranged in four rows of eight each (Fig. 206, *b*, p. 555). They are more delicate, and less perfectly formed than in the skate. In the bulbus arteriosus of one of the American devil-fishes (*Cephalopterus giorna*), the segments increase to thirty-six, are more imperfect than in any of the others, and are supported by three longitudinal angular muscular columns. As the segment-bearing columns, from their shape, project into the cavity of the bulb, and almost obliterate it when the bulb closes, they in this way

[1] "The Relation, Structure, and Function of the Valves of the Vascular System in Vertebrata." (*Trans. Roy. Soc. Edin.*, 1864.)

bring the free margins of the segments together. The orifice of the bulbus arteriosus, however, is not closed by the imperfect segments referred to; this being guarded by two well-formed and fully-developed tri-semilunar valves, the one of which is situated at the beginning, the other at the termination, of the bulb. In the bulbus arteriosus of the gray shark (*Galeus communis*), we have a slightly different arrangement, the two rows of segments of which the valve is composed being connected with each other by means of tendinous bands, resembling chordæ tendineæ. In the bulbus arteriosus of the lepidosteus (Fig. 207, *b*, p. 555), and that of the basking shark (Fig. 208, *b*, ib.), the same arrangement prevails; the segments being stronger and less mobile, and the tendinous bands which bind the one segment to the other more strongly marked. As the tendinous bands referred to are not in contact with the wall of the bulbus arteriosus, but simply run between the segments, and are in some instances, as in the basking shark, very powerful, they must be regarded in the light of sustaining or supporting structures; their function being probably to prevent eversion of the segments. Other examples might be cited, but sufficient have been adduced to show that the form, as well as the number and arrangement, of the segments is adapted to the peculiar wants of the structure in which the segments are situated; and it ought not to be overlooked, that when a multiplicity of segments is met with in an actively moving organ, the muscles and valves act together.

If attention be now directed to the auriculo-ventricular valves of the fish and reptile, similar modifications as regards the number of the segments, and the presence or absence of chordæ tendineæ and analogous structures, present themselves. Thus, in the heart of the serpent (*Python tigris*), the two crescentic apertures by which the blood enters the posterior or aortic division of the ventricle are each provided *with a single semilunar valve.* The same may be said of the aperture of communication between the left auricle and ventricle of the crocodile (*Crocodilus acutus*) and of the sturgeon (*Accipenser sturio*, Linn.). In the heart of the Indian tortoise (*Testudo indica*, Vosmaer), the left auriculo-ventricular orifice is guarded *by a single membranous fold*, the right orifice having in addition *a slightly projecting semilunar ridge*, which extends from the right ventricular wall, and may be regarded as the rudiment of the fleshy valve which guards the same aperture in birds (Fig. 39, *i*, *j*, p. 214). In the heart of the bulinus, frog-fish, American devil-fish, gray shark, and crocodile, the auriculo-ventricular orifice is guarded by a semilunar valve consisting *of two cusps or segments;* while in the sturgeon, sun-fish, and others, it is guarded *by four, two larger and two smaller.*

So much for the number of the segments constituting the auriculo-ventricular valves in fishes and reptiles; but there are other modifications which are not less interesting physiologically. In the bulinus, frog-fish, and crocodile, the segments of the valves are attached to the auriculo-ventricular tendinous ring, and to the sides of the ventricle, and *have no chordæ tendineæ.* In the sun-fish the valve is likewise destitute of chordæ tendineæ; but in this instance the muscular fibres are arranged *in the direction of the free margins of the segments of the valve*, and no doubt exercise an influence upon them. In the gray shark the membranous folds forming the segments *are elongated at the parts where they are attached to the ventricular walls*, these elongated attachments being more or less split up, so as to resemble *chordæ tendineæ.*

In the American devil-fish the auriculo-ventricular valve consists of two strong, well-developed, membranous folds, which, like the preceding, are attached by elongated processes to the interior of the ventricular wall; *these processes consisting of distinct tendinous slips*, which are attached *to rudimentary musculi papillares.*

In the sturgeon *three tendinous chords from rudimentary musculi papillares* are seen to extend into the half of each of the segments; while in the left ventricle of the dugong, *six chords proceeding from tolerably well-formed musculi papillares are distributed to the back, and six to the margins of each of the segments.* It is, however, in the bird and mammal, particularly the latter, that the musculi papillares are most fully developed, and the chordæ tendineæ most numerous—the number of tendinous chords inserted into each of the segments amounting to eighteen or more. As the chordæ tendineæ of the ariculo-ventricular valves are attached either to the interior of the ventricle, or to the musculi papillares or carneæ columnæ, it is evident that the closure of the ventricle must influence both valves and chords to a greater or less extent. That, however, the presence of muscular substance does not impair the efficiency of the valves appears from this—that some valves are partly muscular and partly tendinous, a few being altogether muscular. Thus, in the heart of the cassowary, the right auriculo-ventricular orifice is occluded by a valve, which is partly muscular and partly tendinous; the muscular part, which is a continuation of two tolerably well-formed musculi papillares, extending into the tendinous substance of the valve, where it gradually loses itself. In the right ventricle of the crocodile, a muscular valve, resembling that found in the right ventricle of birds, exists.

In some birds the right auriculo-ventricular valve is altogether muscular. It is usually described as consisting of two parts, from the fact of its dependent or free margin being divided into two portions by a spindle-shaped muscular band, which connects it with the right ventricular wall. As, however, the valve consists of one continuous fold towards the base of the right ventricle, and the two portions into which its free margin is divided are applied

during the systole not to each other but to the septum, the valve in reality consists of a singular muscular flap or fold, as shown at *i* of Fig. 161, p. 493

The muscular flap or fold extends from the edge and upper third of the septum posteriorly to the fleshy pons anteriorly. It opens towards the interior of the right ventricle in a direction from above downwards, and is deepest at the edge of the septum posteriorly. As it gradually narrows anteriorly (*i*), it is somewhat triangular in shape, its dependent and free margin describing a spiral which winds from behind forwards, and from below upwards. The valve, from its shape and structure, might not inappropriately be termed the musculo-spiral valve. It is well seen in the right ventricle of the emu, swan, turkey, capercailzie, and eagle. The muscular valve of the bird is composed of the fibres entering into the formation of the several layers of the right ventricular wall (the ventricular wall in fact bifurcates or splits up towards its base); the external layers forming the outer wall of the valve, the internal layers, which are slightly modified, forming the inner. If the muscular valve be regarded as an independent formation, which it can scarcely be, it will be best described as a structure composed of fibrous loops, these loops being of three kinds, and directed towards the base—the first series consisting of spiral, nearly vertical fibres, forming a somewhat acute curve; the second series consisting of slightly oblique spiral fibres, forming a larger or wider curve; and the third series consisting of still more oblique fibres, and forming a still greater curve. As the fibres composing the different loops act directly upon each other when the ventricles close, the object of the arrangement is obviously to supply a movable partition or septum which shall occlude the right auriculo-ventricular opening during the systole. The manner in which the several muscular loops act is determined by their direction. Thus, the more vertical ones during the systole, in virtue of their shortening from above downwards, have the effect of flattening or opening out the valvular fold, and in this way causing its dependent or free margin to approach the septum. The slightly oblique fibres, which shorten partially from above downwards, but principally from before backwards, assist in this movement by diminishing the size of the right auriculo-ventricular orifice in an antero-posterior direction—it remaining for the very oblique and transverse fibres, which shorten from before backwards and from without inwards, to complete the movement by pressing the inner leaf of the fold directly against the septum—an act in which the blood plays an important part, from its position within the valve; this fluid, according to hydrostatic principles, distending equally in all directions, and acting more immediately on the dependent or free margin of the valve, which is very thin and remarkably flexible. When a vertical section of the fold forming the right auriculo-ventricular muscular valve of the bird is made, that portion of it which hangs free in the right ventricular cavity is found to be somewhat conical in shape, the thickest part being directed towards the base, where it has to resist the greatest amount of pressure; the thinnest corresponding to its dependent and free margin, where it is applied to and supported by the septum. The upper border of the fold is finely rounded, and in this respect resembles the convex border which limits the right ventricle of the mammal towards the base.

The spindle-shaped muscular band (Fig. 161, *j*, p. 493), which from its connection may be said to command the upper and lower portions of the right ventricle interiorly, is obviously for the purpose of co-ordinating the movements of the muscular valvular fold (*i*); and as its position and direction nearly correspond with the position and direction of the musculus papillaris situated on the right ventricular wall of the mammal, it is more than probable that it forms the homologue of this structure. Indeed this seems almost certain from the fact that if the ventricles of the bird be opened anteriorly and the band referred to (*j*) contrasted with the anterior musculus papillaris of the left ventricle (*g*), both are found to occupy a similar position. The fleshy band is therefore to the muscular valve of the right ventricle, what the anterior musculus papillaris and its chordæ tendineæ are to the segments of the bicuspid valve. Compared with the tricuspid valve of the mammal, the muscular valve of the right ventricle of the bird is of great strength. As, moreover, it applies itself with unerring precision to the septum (*e*), which is slightly prominent in its course, its efficiency is commensurate with its strength. The more perfect respiration of the bird as compared with that of the mammal seems to require the more powerful and active muscular valve; the right ventricle having to force the blood into the lungs, air sacs, &c. The prominence on the septum alluded to is very slight, and might escape observation, were it not that immediately below the prominence the septum is hollowed out to form a spiral groove of large dimensions. This groove, like the valve, runs in a spiral direction from behind forwards and from below upwards, and when the valve is applied to the septum during the systole, converts the right ventricular cavity into a spiral tunnel, through which the blood is forced, on its way to the pulmonary artery. The efficiency of the right auriculo-ventricular muscular valve in birds clearly shows that large apertures may be occluded by purely muscular arrangements and by vital movements; and it is important to bear this fact in mind, as it shows how the musculi papillares in mammals, by their elongating and shortening, may take part in the opening and closing of the mitral and tricuspid valves. In addition to the muscular valve of the bird described, it may be well to state that in the serpent the opening between the right and left ventricles occurs as a spiral slit in the septum. It is guarded by two projecting muscular surfaces, which are rounded off for the purpose. The orifices of many of the

venous sinuses are closed by purely muscular adaptations; the fibres in such instances running parallel with the slit-like opening (Fig. 201, I, *a*, *b*, p. 550), and being continuous with two or more bundles of fibres (*c*, *d*), which supply the place of musculi papillares. From the great variety in the shape and structure of the auriculo-ventricular valves, and from the existence in almost all of tendinous chords, which connect them with actively moving structures, there can, I think, be no doubt that these valves possess an adaptive power traceable in a great measure to the centripetal and centrifugal power residing in muscle.

As it would occupy too much time to give a detailed account of the numerous auriculo-ventricular valves to which allusion has been made, I have selected for description the auriculo-ventricular valves of the mammal, and those of man more particularly.

§ 165. Intricate Structure of the Bicuspid and Tricuspid Valves in Mammalia; Relations of the Chordæ Tendineæ to the Valves and to the Musculi Papillares.

The auriculo-ventricular valves, known as the bicuspid and tricuspid valves, are composed of segments which differ in size, and are more or less triangular in shape. They are much stronger than the segments composing the aortic and pulmonic semilunar valves, which in some respects they resemble in structure and function. The segments of the bicuspid and tricuspid valves are very dense, and quite opaque, unless at the margins and apices, where they are frequently remarkably thin. They unite at the base where thickest to form tendinous zones, which are attached to the fibrous rings surrounding the auriculo-ventricular orifices (Plate lxxxv., Fig. 5, p. 325). The auriculo-ventricular fibrous rings have been variously described, the majority of investigators regarding them as strongly pronounced structures, which afford attachment, not only to the auriculo-ventricular valves, but to all the muscular fibres of the auricles and ventricles. A careful examination of these rings in boiled hearts has led me to a different conclusion. They afford attachment to the muscular fibres of the auricles and to the valves, *but to almost none of the muscular fibres of the ventricles*. They are most fully developed anteriorly, and on the septum, where they form a dense fibrous investment. The left ring, like everything else pertaining to the left ventricle, is more fully developed than the right; but neither the one nor the other can compare in breadth or thickness with the pulmonic or aortic fibrous rings. The influence exerted by the auriculo-ventricular fibrous rings in conferring rigidity on the auriculo-ventricular orifices is consequently not great. The position of the segments of the bicuspid and tricuspid valves in the auriculo-ventricular orifices, and their relation to the musculi papillares, are deserving of attention. The left auriculo-ventricular orifice is provided with a valve consisting of two major or principal segments, and two minor or smaller segments, which are placed between the principal ones. The major segments are unequal in size and form; their shape and depending position resembling a bishop's mitre inverted, hence the epithet *mitral* or *bicuspid* applied to this valve. The larger of the major segments is suspended obliquely between the left auriculo-ventricular and aortic openings, and occupies a somewhat internal and anterior position; the smaller one, which runs parallel to it, occupying a more external and posterior position. The right auriculo-ventricular orifice is supplied with a valve composed of three major or principal segments, and three minor or smaller intermediate segments. From this the right auriculo-ventricular valve has been named *tricuspid* to distinguish it from the bicuspid or mitral one. The three principal segments forming the tricuspid valve vary in size—the smallest running parallel with the septum; the largest being placed anteriorly and inclined to the right side; the one which is intermediate in size occupying a more posterior position. The segments, whatever their size, are attached by their bases to the auriculo-ventricular fibrous rings, and by their margins and apices (by means of the chordæ tendineæ) to the spiral musculi papillares.

FIG. 209.—Anterior segment of human bicuspid valve. Shows the threefold distribution of the chordæ tendineæ from above downwards, and from the mesial line towards the margins of the segment. *z*, Base of segment; *x*, apex of segment; *r*, *r'*, *s*, *s'*, chordæ tendineæ from anterior portions (*a*, *c*) of right and left musculi papillares, bifurcating and losing themselves in margins of segment; *b*, *d*, posterior portions of right and left musculi papillares, which send chordæ tendineæ to posterior segment of mitral valve. (Drawn from a dissection by the Author, 1864.)

The segments of the bicuspid valve, to which the following description, drawn from an extensive examination by me of mammalian hearts,[1] more particularly applies, consist of a reduplication of the endocardium, or lining

[1] Of the hearts examined, those of man, the elephant, camel, whale (*Physalus antiquorum*, Gray), mysticetus, horse, ox, ass, deer, sheep, seal, hog, porpoise, monkey, rabbit, and hedgehog, may be mentioned.

membrane of the heart, containing within its fold large quantities of white fibrous tissue, to which is to be added a considerable proportion of yellow elastic tissue (Fig. 209). The presence of yellow elastic tissue was first detected by the late Sir W. S. Savory, and after him by Professor Donders.[1] The white fibrous tissue greatly preponderates, and is derived principally from the chordæ tendineæ, which split up into a large number of brush-shaped expansions, prior to being inserted into the segments. The fibrous expansions, which assume the form of bands, may consequently be regarded as prolongations of the chordæ tendineæ. They are analogous, in many respects, to similar bands in the semilunar valves (Fig. 205, B, *s*, *t*, p. 554); the only difference being that, in the semilunar valves, the bands referred to, instead of being free, as in the present instance (Fig. 209, *r*, *r*, *s*, *s*, p. 559), are involved in the valvular substance.

As each of the segments composing the bicuspid valve, like the left ventricle itself, is bilaterally symmetrical, and as each musculus papillaris sends tendinous bands or chords (*chordæ tendineæ*) to both segments of the bicuspid, it will be convenient when speaking of these structures to consider each musculus papillaris as essentially consisting of two portions, an anterior portion (Fig. 209, *c*, *p*, p. 559) which gives off two (more commonly three) tendinous bands or chords (*r*, *r*) to that half of the anterior segment of the bicuspid valve which is next to it: and a posterior portion (*d*) which also gives off three tendinous chords; these being inserted into the adjacent half of the posterior segment.[2]

The tendinous chords (*chordæ tendineæ*) are divided into no fewer than eighteen sets; six being distributed to the free margins of the segment, six to the mesial line of the segment, and six to intermediate points. These are largest and most pronounced on the back of the segment, and vary very little as regards number and position. While they are largest and strongest in the middle of the segment they are thinnest and weakest at the margins, where they are, in some cases, as thin as tissue paper. As the segments are composed of tough material, placed equi-distant, and radiate and terminate in brush-shaped expansions, they confer a degree of strength on the segment which cannot be exceeded by any other arrangement. Each segment presents the appearance of a girder bridge, where struts and stays are employed to prevent undue strain upon any one part. This principle at once secures great strength and lightness.

The design revealed by the general plan of the bicuspid valve, and its elaborate construction, indicate its importance as a physiological unit. It is as necessary to the circulation as the rima glottidis is to the respiration. Every drop of blood which enters the left ventricle of the heart and is propelled through the body must come in contact with it and, in a sense, be measured by it. It is the chief of the blood sluices or gates, and health largely depends on its integrity. A diseased bicuspid valve produces in many cases untold misery and anxiety, and in not a few instances an early painful death.

The bicuspid valve does not owe its existence to irritability, extraneous stimulation, or environment. It is a fundamental structure, and forms an integral part of the heart, with which it is coeval. It is no chance product. Neither is it the result of evolution or natural selection. It is part of a great and intricate system of valves which guide and control the blood in its passage through the heart, and can only be adequately accounted for by a First Cause, design, and predetermined adaptation. It is an outstanding example of "means to ends," having delegated to it the performance of very special work. Considering its importance structurally and functionally, the time devoted to its production (the period of gestation) cannot be regarded as excessive. Its history *in utero* and during adult life causes it to rank with other great structures which make or mar life.

As the brush-shaped expansions of the chordæ tendineæ of the bicuspid taper from above and from within outwards, it follows that the segment diminishes in thickness from the base (*z*) towards the apex (*x*), and from the mesial line towards the periphery or margin; the basal and central portions of the segment being comparatively very thick, the apical and marginal portions very thin; so thin, indeed, that in some hearts, particularly in the right ventricle, they present a cobwebbed appearance. As, further, the marginal portions form the counterparts of the lunulæ in the semilunar valves, and are those parts of the segments which come into accurate apposition when the valve is in action, they are entitled to special consideration. When a perfectly healthy mitral valve from an adult—or still better, from a fœtus at the full time or soon after birth—is examined, the portions referred to are found to be of a more or less crescentic shape (*vide* that part of the bicuspid valve to which the chordæ tendineæ marked *r*, Fig. 209, p. 559, are distributed), and so extremely thin, that the slightest current in the fluid in which they are examined causes them to move like cilia. The physiological value of this delicacy of structure, and consequent mobility, is very great, inasmuch as the most trifling impulse causes the marginal parts of the segments, which are naturally in juxtaposition, to approach towards or recede from each other with great alacrity. The segments of

[1] Professor Donders describes the yellow elastic tissue as being most abundant in the upper surface of the segments.

[2] The musculi papillares in the human and other hearts either bifurcate or show a disposition to bifurcate at their free extremities, so that the division of the chordæ tendineæ into two sets is by no means an arbitrary one.

the bicuspid valve, it will be seen, consist of a reduplication of the endocardium or lining membrane of the heart, supported or strengthened in all directions by eighteen tendinous, brush-shaped expansions; these expansions being symmetrical and arranged with much precision, according to a principle which is seldom departed from. In addition to the reduplication of the lining membrane and the tendinous expansions described, Lancisi,[1] Senac,[2] and Kürschner[3] have ascertained that there is a slight admixture of true muscular fibres.[4] When a segment of the bicuspid valve is examined by being held against the light, or by the aid of a dissecting lens, it is found to consist of tendinous striæ running transversely, obliquely, and more or less vertically; the striæ of opposite sides being so disposed that they mutually support and act upon each other—an arrangement productive of great strength, and one which secures that the segments shall be at once tightened or loosened by the slightest shortening or lengthening of the musculi papillares. The minor or accessory segments of the bicuspid valve resemble the principal ones in structure and general configuration. They are, comparatively speaking, very thin; and the chordæ tendineæ inserted into them differ from those inserted into the principal segments, in having a more vertical direction, and in being longer and more feeble. The description given of the bicuspid valve applies, with trifling alterations in particular instances, to the tricuspid, if allowance be made for an additional large segment, and three or more accessory segments. With regard to the smallest of the three large segments forming the tricuspid, I have to observe that, in all probability, it is simply an over-developed accessory segment; the so-called tricuspid valve being in reality bicuspid in its nature. Nor is this to be wondered at, when it is stated that the right ventricle is a segmented portion of the left, and partakes of its bilateral symmetry even in matters of detail. The opinion here advanced is by no means new, but it appears to me that the point has not been sufficiently investigated, and we are in want of details and statistics regarding it. In ten human hearts which I examined, no less than four had well-marked bicuspid valves in both ventricles (Fig. 213, p. 564): and on looking over a large collection of miscellaneous hearts in the Museum of the Royal College of Surgeons of England, I found that nearly a third of them had the peculiarity adverted to; if indeed that can be called peculiar, which seems to me to be typical. When two principal segments, with two or more accessory segments, occlude the right auriculo-ventricular orifice, the chordæ tendineæ are arranged as in the segments of the bicuspid valve already described. The segments of the tricuspid valve are thinner than those of the bicuspid. This is traceable to the fact that the right heart is more feeble, and has less work to perform, than the left one. As the chordæ tendineæ are inserted into every portion of the bicuspid and tricuspid valves, and freely decussate with each other in all directions, by means of their terminal brush-shaped expansions; as, moreover, the chordæ tendineæ are of infinite variety as regards length and strength, those at the base of each segment being long and exceedingly strong, while those at the margins and towards the apices are short, and in some instances as delicate as hairs, it follows that every part of the bicuspid and tricuspid valves is under the control of the conical-shaped spiral musculi papillares, whose power to shorten and lengthen is now well established.[5] There can be little doubt that the chordæ tendineæ are to be regarded as the satellites of the constantly moving musculi papillares, under whose guidance they have to perform, not only a very important, but a very delicate function, and one which could not by any possibility be accomplished by a simply mechanical arrangement.

§ 166. The Bicuspid and Tricuspid Valves of the Mammal in Action.

The theories which have long divided the opinions of physiologists as to the action of the bicuspid and tricuspid valves are two in number; one sect maintaining that the valves *are acted upon mechanically by the blood*, as if they were composed of inanimate matter; the other believing that *they form part of a living system*, their movements being traceable to their connection with the musculi papillares, which, as explained, have the power of elongating and shortening.

According to the mechanical theory, the segments of the valves are supposed to be *passively* floated up by the blood, which acts upon them from beneath during the systole, and brings their edges or free margins into such accurate apposition as enables the segments completely to occlude the auriculo-ventricular orifices. In these movements *the musculi papillares and carneæ columnæ* are said *to take no part;* the chordæ tendineæ acting *mechanically*, like so many stays, to prevent eversion of the segments in the direction of the auricles.

According to the vital theory, the segments of the valves are supposed to be from the first *under the control of the musculi papillares;* these structures, when they shorten, drawing the lips or free margins of the segments

[1] De Motu Cordis.

[2] Traité de la Structure du Cœur, livre i. p. 76.

[3] Wagner's Handwörterbuch, art. "Herzthätigkeit."

[4] According to Mr. Savory's observations the muscular fibre is found more particularly at the upper or attached border of the valves.

[5] Dr. John Reid states from experiment, that the carneæ columnæ act simultaneously with the other muscular fibres of the heart, and that the musculi papillares are proportionally more shortened during their contraction than the heart itself taken as a whole. He attributes this to the more vertical direction of the musculi papillares, and to their being free towards the base and in the direction of the ventricular cavities.

closely together in the axes of the auriculo-ventricular openings to form two impervious cones, the apices of which project downwards into the ventricular cavities.

In these movements, it is said, *the blood takes no part,* the chordæ tendineæ, which are regarded as the proper tendons of the musculi papillares, acting as adjusters or adapters of the segments, a function which their varying length and strength readily enables them to perform.

In the valvular controversy, as in most others, a certain amount of truth is to be found on either side; and I have to express my conviction that both theories (conflicting though they appear) are virtually correct so far as they go, but that neither the one nor the other is sufficient of itself to explain the gradual, and to a certain extent self-regulating, process by which the auriculo-ventricular valves are closed and kept closed. On the contrary, I believe that the closure is effected partly by *mechanical* and partly by *vital* means. In other words, that the blood towards the end of the diastole and the beginning of the systole forces the segments in an upward direction, and causes their margins and apices to be so accurately applied to each other as to prevent even the slightest regurgitation; whereas during the systole, and towards the termination of that act, the valves are, by the shortening of the musculi papillares, dragged down by the chordæ tendineæ into the ventricular cavities to form two dependent spiral cones.

Granting that my explanation is correct, there is yet another point *as to the manner of the closure,* to which I am particularly anxious to direct attention, as it is of primary importance, and appears to have hitherto escaped observation. I refer to the spiral form assumed by the blood in the ventricular cavities, which, as has been already explained, causes it to act in *spiral waves* (Fig. 176, *j*, *q*, p. 510) mechanically on the under surface of the segments, with the effect of *twisting and wedging them into each other in a spiral upward direction* (Figs. 212, 213, *m*, *i*, *n*, *r*, *s*, p. 564). The segments of the aortic and pulmonic valves are twisted and wedged into each other by the refluent blood in a direction from above downwards (Fig. 210, *v*, *w*, *x*; *r*, *s*, *t*, p. 564). I allude also to the spiral course pursued by the musculi papillares (Fig. 175, *m*, *n*, p. 509); these structures as the systole advances shortening in such a manner as to occasion the spiral descent of the segments into the ventricular cavities (Fig. 210, *m*, *n*, *r*, *s*, p. 564) to form *two spiral dependent cones,* the apices of which are directed towards the apices of the ventricles. As the decrease of the blood in the ventricles is followed by a corresponding increase in the auricles, the blood in the auricles assists in keeping the free margins and apices of the segments from being everted by the uniform pressure exercised on them by the blood in the ventricles during the systole. From this account of the closure of the auriculo-ventricular valves it will be evident that the bicuspid and tricuspid valves form two movable partitions or septa, which rise and fall during the diastole and systole of the heart, in the same way that the diaphragm rises and falls during expiration and inspiration. The advantage of such an arrangement is obvious. *When the ventricles are full of blood,* and the auricles empty, or comparatively so, the valvular septa are convex towards the base of the heart, and protrude into the auricular cavities (Figs. 212, 213, p. 564). When, on the other hand, *the auricles are full of blood,* and the ventricle all but drained of it, the valvular septa are dragged downwards into the ventricular cavities to form inverted cones (Fig. 210, p. 564). Certain portions, therefore, of the auriculo-ventricular cavities are common alike to the auricles and to the ventricles; and it is important to note this fact, as the valvular septa, by their rising and falling, at one time increase the size of the ventricular cavities, while they diminish the auricular ones, and *vice versâ.* The principal object gained by the descent of the segments into the ventricles is the diminution of the ventricular cavities towards the base; the dependent cones formed by the valves fitting accurately into the conical-shaped interspaces situated between the slanting heads of the musculi papillares and the auriculo-ventricular fibrous rings. As the musculi papillares, when the ventricles close, mutually embrace and twine round each other, the obliteration of the ventricular cavities is readily effected.

An important inference to be deduced from the spiral nature of the ventricular fibres and ventricular cavities and *the undoubted spiral action of the auriculo-ventricular valves,* is the effect produced on the blood as it leaves the ventricles, that fluid being projected by a wringing or twisting movement, which communicates to it *a gliding, spiral motion.* This view is favoured by the spiral inclination of the sinuses of Valsalva to each other, these structures—as has been already explained—gradually introducing the blood so projected into the vessels. The quaint and suggestive phrase "wringing the heart's blood" is consequently true in fact. It is not a little curious that other hollow viscera besides the heart, as the bladder and uterus, also expel their contents spirally.

167. The Mechanical and Vital Theories of the Action of the Bicuspid and Tricuspid Valves considered.

That the theory which attributes the closure of the auriculo-ventricular valves to the mechanical floating up of the segments from beneath by the blood, forced by the auricles into the ventricles, distending equally in all

directions, is of itself inadequate to explain all the phenomena, is exceedingly probable from analogy and the nature of things; for if a merely mechanical arrangement of parts was sufficient for the closure of the auriculo-ventricular orifices, then, it may be asked, why were these apertures in birds and mammals not furnished with sigmoid or semilunar valves similar in all respects to those met with in the veins and arteries? The answer to this question is no doubt to be found in the nature of the structures in which the valves are situated, as well as in the circulation itself.[1] In the veins, as is well known, the movements of the blood are sluggish—the closure of the vessels being feeble, and consequently not calculated to interfere to any great extent with the closing of the valves. In the arteries, where the circulation is more vigorous, and the closure of the vessels more decided, the valves are surrounded by dense fibrous rings, which protect them from the opening and closing alike of the ventricles and vessels. No such fibrous rings occur in the bulbus arteriosus of fishes, and as a consequence the valves are exposed to the influence of muscular movements. To obviate this difficulty *the segments of the valves are not only increased in number, but chordæ tendineæ*, in the shape of tendinous bands, *begin to make their appearance.* In the auriculo-ventricular valves of fishes and reptiles, *chordæ tendineæ in various stages of development are discovered*, these being attached to the interior of the ventricle *to more or less fully developed musculi papillares.* The musculi papillares in fishes and reptiles are in no instance so well marked as in birds and mammals. As we rise in the scale of being, and the requirements of the circulation become greater, it will be observed *that the relation of the segments to actively moving structures* becomes more and more defined. In the ventricle of the fish, as I pointed out, the fibres proceed in wavy lines from base to apex, and from apex to base, from without inwards and circularly; so that the organ closes and opens very much *as one would shut and open the hand.* In the reptilia the external and internal fibres pursue a slightly spiral direction—*the ventricles rotating more or less when in action.* In the cold-blooded animals, as is well known, the circulation is languid or slow, so that an arrangement of valves similar in some respects, though more complex than that which exists in the veins and venous sinuses and in the arteries, amply suffices. In the hearts, however, of the warm-blooded animals, where the ventricles are composed entirely of spiral muscular fibres, and where the circulation, on account *of the sudden twisting and untwisting of the fibres, is rapid*, a system of valves which will act with greater alacrity and precision is absolutely necessary. But functional precision implies structural excellence; and hence that exquisite arrangement of parts in the auriculo-ventricular valves of mammals, whereby every portion of every segment (by reason of the ever-varying length and strength of the chordæ tendineæ) bears a graduated relation to the musculi papillares and carneæ columnæ. Although the partial closing of the valves during the diastole is occasioned by the uniform expansion of the blood owing to the force exercised upon it by the closure of the auricles, still it must be evident to all who reflect, that this cause is not of itself adequate to the complete closure, and for a very obvious reason. The blood, which is the expanding force, enters the ventricular cavities by the auriculo-ventricular orifices, which are the orifices to be closed. Once in the ventricles, however, the blood has no inherent expansive power by which it can of its own accord entirely shut off or close the apertures by which it entered. This act requires for its consummation the force exercised by the closure of the ventricles at the commencement of the systole. Admitting, however, that the expansion of the blood was adequate to the closure of the auriculo-ventricular valves at one period,—say at the end of the ventricular diastole, when the ventricles are full of blood and the auriculo-ventricular orifices widest,—it is scarcely possible that it could keep them closed towards the end of the systole, when the auriculo-ventricular orifices are greatly diminished in size and the blood itself all but ejected. A regulating and motor power, therefore, in addition to the blood, for adapting the different portions of the segments of the valves to the varying conditions of the auriculo-ventricular orifices and cavities during the systole, seems requisite. Such a power, in my opinion, resides in the conical-shaped spiral musculi papillares with their proper tendons, the chordæ tendineæ.

That the theory which ascribes the closing of the auriculo-ventricular valves entirely "to the contraction of the musculi papillares," is likewise of itself insufficient, appears for the following reasons:—

First, If the valves which, at the commencement of the ventricular diastole, are floated mechanically upwards, and have their edges approximated by the blood towards the termination of the diastole, were dragged upon at the beginning of the systole from above downwards, or in an opposite direction to that in which the force by which they were brought together acts, the segments of the valves, instead of being further approximated, would inevitably be drawn asunder, and regurgitation to a fatal extent supervene.

Second, By such an arrangement, as Dr. Halford has satisfactorily shown, the cavities of the ventricles would not only be materially diminished at a very inconvenient time, but a certain amount of the

[1] According to Harvey, Lower, Senac, Haller, and others, the auricles contract with a very considerable degree of energy. In a quantity of fluid submitted to compression, the whole mass is equally affected and similarly in all directions. Dr. George Britton Halford attributes the closure of the auriculo-ventricular valves entirely to the pressure exercised by the auricles on the blood forced by them into the ventricles. That, however, this is not the sole cause, will be shown further on.

force required for the expulsion of the blood from the ventricular cavities would be expended in closing the valves.

The auriculo-ventricular valves are so constructed and so placed that they equally obey the impulses communicated by the blood and by the musculi papillares. Thus, as the blood finds its way into the ventricular cavities, the segments of the valves are floated upwards upon its surface like the leaves of water-plants. This floating upwards brings the delicate margins of the segments into such accurate apposition, that they are closed the instant the ventricles begin to contract, an arrangement which effectually prevents regurgitation. The sudden closure of the ventricles upon their contained blood has the effect of momentarily forcing the valves in an upward direction into the auricular cavities—a movement limited by the chordæ tendineæ, which effectually prevent eversion. The upward movement is gradually checked as the systole advances and the musculi papillares shorten; the valves being made to descend upon the blood rapidly disappearing from the ventricular cavities. In this movement the valves form depending cones, the sides of which fit accurately into the conical spaces formed at the base of the heart by the slanting heads of the musculi papillares. The ventricular cavities are diminished towards the base of the heart by the depending position of the segments of the mitral and tricuspid valves towards the end of the systole. If to this be added the fact that, at this particular period, the musculi papillares twine into and around each other so as to become strongly embraced, and the ventricles are greatly diminished from below upwards and from without inwards, it will not be difficult to understand how the ventricular cavities are drained of blood during the systole. Plate xcvii.

Fig. 210.

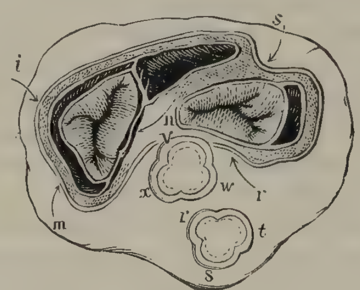


Fig. 211.

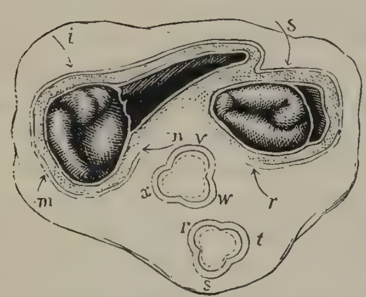


Fig. 212.

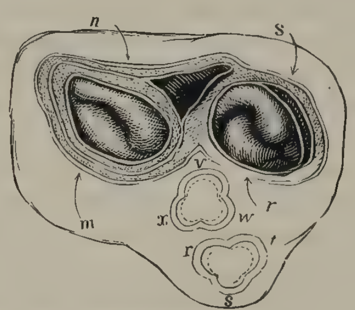


Fig. 213.

Figs. 210, 211, and 212.—Show the bicuspid (r, s) and tricuspid (m, i, n) valves in action (human); how the segments, acted upon by the spiral columns of blood, *roll up* from beneath towards the end of the diastole (Fig. 210); how, at the beginning of the systole, they are wedged and twisted into each other, on a level with the auriculo-ventricular orifices (Figs. 212 and 213); and how, if the pressure exerted be great, they project into the auricular cavities (Fig. 212). When the bicuspid and tricuspid valves (Fig. 210, m, n; r, s) are open, the aorta and pulmonic semilunar valves (v, w, x; r, s, t) are closed. When, on the other hand, the bicuspid and tricuspid valves are closed (Figs. 211, 212, and 213, r, s; m, i, n), the aortic and pulmonic semilunar ones (v w, x; r, s, t) are open. To this there is no exception (the Author, 1864).

Fig. 213.—Shows a human heart with a true bicuspid valve in both ventricles as seen in action at the commencement of the systole. The letters are the same as in Figs. 210, 211, and 212 (the Author, 1864).

Note.—The spiral downward movement of the bicuspid and tricuspid valves (Fig. 210) has only been partly shown, from the difficulty experienced in representing spiral cavities.

It therefore appears to me that the auriculo-ventricular valves are alternately active and passive, there being a brief period when they are neither the one nor the other.

The passive state corresponds to the diastole or opening of the ventricles; the active state, to the systole or closing; and the neutral or intermediate state, to that short interval which embraces the termination of the diastole and the commencement of the systole. In speaking of the closure of the valves, it is of great importance to remember that the action, although very rapid, is a strictly progressive one, and necessarily consists of stages. In this, however, as in many other vital acts, it is often very difficult, if not indeed impossible, to say precisely where the one stage terminates and the other begins. As the action of the valves is, to a certain extent, dependent upon and induced by the action of the auricles and ventricles, the following slight differences as regards time are to be noted. The passive

[1] Dr. Halford states his belief, "that the segments of the valves are forced even beyond the level of the auriculo-ventricular orifices, and in this way become convex towards the auricles, and deeply concave towards the ventricles." ("On the Time and Manner of Closure of the Auriculo-ventricular Valves." Churchill, London, 1861.) In his zeal for the enlarged accommodation of the ventricles, Dr. Halford forgets that the auricles are equally entitled to consideration, and that it is unfair to give to the one and take from the other; for if, as he argues, the segments of the valves form convex partitions, whose convexities throughout the entire systole of the ventricles point in the direction of the auricles, the space beyond the level of the auriculo-ventricular orifices is appropriated from the auricles without compensation. As, however, such an arrangement could not fail materially to inconvenience the auricles when *they are fullest* of blood, we naturally turn to the ventricles for redress. The additional space required is, as I have already shown, supplied by the descent of the segments of the bicuspid and tricuspid valves towards the end of the systole, when the ventricles are almost drained of blood.

state of the valves corresponds to that period in which *their segments are floated mechanically upwards, and their margins partially approximated* by the blood forced by the auricles into the ventricles ; the neutral state, to that almost inappreciable interval which succeeds the sudden closure of the ventricles, in which the blood set in motion is arranged in spiral columns, and acts in such a way as not only instantly closes the valves, but *screws and wedges the segments thereof into each other in an upward spiral direction.*[1] The active state corresponds to the period occupied by the progressive closing of the ventricles. During this period *the valves are dragged forcibly downwards by the shortening of the musculi papillares, in an opposite direction to that by which they ascended ; and are twisted into or round each other to form spiral dependent cones.* In the active stage, as in the neutral, the blood acts from beneath, and keeps the delicate margins and apices of the segments of the valves in accurate contact. The appearances presented are represented at Figs. 210 to 213, p. 564.

That the foregoing is the true explanation of the gradual approximation and continued closure of the auriculo-ventricular valves, there can, I think, be little doubt, both from the disposition and structure of the parts, and from experiment. If, for example, the coagula be carefully removed from perfectly fresh ventricles, and two rigid tubes of appropriate calibre be cautiously introduced past the semilunar valves, and securely fixed in the aorta and pulmonary artery,[2] and the preparation be sunk in water until the ventricular cavities fill, it will be found, when one of the tubes, say that fixed in the aorta, is gently blown into, that the segments of the bicuspid valve roll up from beneath in a spiral direction (Fig. 210, *r*, *s*, p. 564), in a progressive and gradual manner ; each of the two larger or major segments, by folding upon itself, more or less completely, in a direction from within outwards, forming itself into a provisional or temporary cone, the apex of which is directed towards the apex of the left ventricle (*first stage in which the crescentic margins and apices of the segments are slowly approximated by the uniform expansion of the blood forced into the ventricle by the auricle*). As the pressure exerted by the breath is gradually increased, and the action of the valve is further evolved, the segments, folded upon themselves as described, *are gradually elevated, until they are on the same plane with the auriculo-ventricular fibrous ring*, where they are found to be spirally wedged and screwed into each other, and present a level surface above (Fig. 211, *r*, *s*, p. 564).

At this, the second stage of the closure, the crescentic margins of the segments are observed to be accurately applied to each other, *to form two perpendicular crescentic walls*, which accord in a wonderful manner with similar walls formed by the union of the semilunar valves (Fig. 203, C, *b*, p. 553) ; in fact the manner of closure is, to a certain extent, the same in both ; the segments in either case being folded upon themselves by the blood, and presenting delicate crescentic margins, which are flattened against each other in proportion to the amount of pressure employed. When the crescentic margins of the segments are so accurately applied to each other as to become perfectly unyielding, and the distending process is carried beyond a certain point, the bodies or central portions of the segments of the bicuspid and tricuspid valves bulge in an upward direction and protrude into the auricles (Figs. 212 and 213, *m*, *n* and *r*, *s*, p. 564). In the case of the segments of the semilunar valves they bulge in a downward direction into the ventricles (Fig. 204, *v*, *w*, *x* ; *r*, *s*, *t*, p. 554). Compare with Figs. 165 and 166, p. 499.

This completes the first and second stages of the process by which the bicuspid valve is closed ; but the more important, as being the more active and difficult stage, has yet to be reached. *This consists in adapting the segments of the valve to the gradually diminishing auriculo-ventricular orifice ; and in dragging them down into the left ventricular cavity*, to diminish the ventricle towards the base. By this act, the segments, as has been shown, are made to form a spiral dependent cone, an arrangement which renders the obliteration of the left ventricular cavity towards the base a matter of certainty.

The third stage of the closure of the bicuspid valve entirely differs from the first and second stages, inasmuch as the chordæ tendineæ, when the musculi papillares shorten, drag the segments in a downward direction, to adapt them to the altered conditions of the left auriculo-ventricular orifice and left ventricular cavity. That this downward movement actually takes place, is proved as follows :—If a portion of the fluid be withdrawn by applying the mouth to the tube in the aorta, so as to create a certain amount of suction, the segments of the bicuspid valve are found gradually to descend in a spiral direction (Fig. 210, *m*, *n*, p. 564), forming as they do so a spiral cone, whose apex becomes more and more defined in proportion as the suction is increased ; the water in the interior of the left cavity keeping the margins of the segments accurately in apposition, and thereby preserving the symmetry of the cone. If, again, the musculi papillares be cut out of the ventricular walls and made to act in the direction of their fibres, that is, in a spiral direction from left to right downwards, they will be found, in virtue of being connected by the chordæ tendineæ more or less diagonally to either segment of the bicuspid valve, to act simultaneously on that side of the

[1] This act take place just before the blood finds its way into the aorta and pulmonary artery, the amount of pressure required for shutting and screwing home the auriculo-ventricular valves being less than that required for opening the semilunar ones.

[2] Strictly speaking, the tubes should be introduced into the auriculo-ventricular orifices, as it is through these apertures that the blood passes during the dilatation of the ventricles. As, however, the insertion of tubes, however small, into the auriculo-ventricular openings would necessarily prevent the complete closure of the valves, that is one good reason for adopting the plan recommended in the text.

segment which is next to them; the anterior musculus papillaris acting spirally on the margin and apex of the larger or anterior segment; the posterior musculus papillaris acting spirally on the margin and apex of the smaller or posterior segment, in a precisely opposite direction. The effect of these apparently incongruous movements on the segments is very striking.

The space which naturally exists between the segments is gradually but quickly diminished, and the segments twisted into or round each other to form the spiral dependent cone referred to.

This arrangement, I may observe, while it facilitates the spiral movement, absolutely forbids any other.

The closure of the bicuspid valve is rendered perfect by the pressure exercised on the delicate margins of the segments by the spiral columns of blood, as already explained.

By the time the blood is ejected from the left ventricle, and the segments of the bicuspid valve have formed the spiral dependent cone, the left auricle is distended; and due advantage being taken of the extra space afforded by the descent of the bicuspid valve, the blood assumes a spiral, wedge-shaped form, which is the best possible for pushing the segments of the bicuspid valve in an outward direction, these being in the most favourable position for falling away from the ventricular axis towards the ventricular walls. The same phenomena are repeated, with unerring regularity, with each succeeding action of the heart. What has been said of the manner of closure of the bicuspid valve applies, I need scarcely add, with slight modifications to the tricuspid.

§ 168. The Sounds of the Heart: to what owing.

A knowledge of the structure and action of the valves of the heart is necessary to a just comprehension of the sounds of the heart. As regards the mode of their production there is much discrepancy of opinion. Harvey was aware of their existence, and compared them to the sounds produced by the passage of fluids along the œsophagus of the horse when drinking. Laennec was the first strongly to direct attention to them. He described their character, the order of their succession, and showed how a knowledge of them would enable us to detect many cardiac lesions. He has therefore laid the medical profession under lasting obligations. The sounds have been divided for convenience into two, a first and second sound. The first sound is dull, deep, and prolonged; and the second, which follows immediately after the first, is quick, sharp, and more superficial.[1] The second sound was compared by Laennec to the flapping of a valve or the lapping of a dog; the first and second sounds being likened by Dr. Williams to the syllables "lupp, dupp." The first sound immediately precedes the radial pulse, and corresponds with the impulse of the heart against the thorax, the closure and susurrus of the ventricles, the rush of the blood through the aortic and pulmonic valves, and the closing and tightening of the auriculo-ventricular valves and chordæ tendineæ. The second sound coincides with the closure and susurrus of the auricles, the rush of the blood through the auriculo-ventricular orifices into the ventricular cavities, the opening of the auriculo-ventricular valves, and the closing of the aortic and pulmonic valves. As the different substances set in motion by the action of the heart, such as the blood, valves, muscular fibres, &c., are all capable of causing sound, it is reasonable to conclude that the several structures and substances moving at the time the sound is heard are one and all concerned in its production. It is this circumstance, combined with the fact that sound once propagated repeats itself or echoes—sounds of different intensity running into each other—which makes it so exceedingly difficult to determine what actually produces the sounds under consideration. What I mean will be understood when I state, that at the same instant that the ventricles are closing and striking the chest, and while they are forcing their blood through the pulmonary artery and aorta, opening the aortic and pulmonic valves, and closing the mitral and tricuspid ones—at this same instant the heart is rolling within the pericardium, and the venæ cavæ and the pulmonic veins are closing, and forcing their blood into the auricles, which are actively dilating to receive it. The sounds produced by the latter movements are therefore, on our part, unconsciously mixed up with the sounds produced by the former movements, and must be added to them. When, again, the auricles are closing and forcing their blood into the ventricular cavities, when the auriculo-ventricular valves are being pushed aside and opened, and the aortic and pulmonic valves closed, at that same instant the ventricles, the venæ cavæ, and pulmonic veins are actively dilating. The sounds which one hears are consequently numerous and of a mixed character, as regards intensity and duration; and to make matters worse, they run into each other by insensible gradations, sometimes slowly, sometimes suddenly. The sounds in fact merge into each other precisely in the same way that the movements of the different parts of the heart merge into each other. They have their points of maximum and minimum intensity, and it is upon these the physiologist and physician fixes when he attempts to define their nature and duration. Such definitions, I need scarcely add, are more or less arbitrary. The first and second sounds are followed by apparent pauses—the pauses corresponding to the brief intervals which follow the closing of the ventricles and auricles respectively. Thus the dull, deep, prolonged, or first sound is followed by a short pause, while the sharp, short, or second sound is followed by another

[1] These sounds have also been called inferior and superior, long and short, dull and sharp, systolic and diastolic.

and longer pause. The sounds and the pauses which occur between them follow in regular order, and when taken in connection with the closing and opening of the different parts of the heart to which they owe their origin, constitute the rhythm of the heart. They occasionally vary in duration, just as the pulse varies in frequency, and in certain cardiac affections the sounds are increased in number, while the pauses are decreased in duration. When the movements and sounds of the heart are very irregular, the condition is expressed by the term "tumultuous." Various attempts have been made to represent the duration of the sounds and pauses in figures. Thus some authors state that if the number 9 be made to represent one complete pulsation, the first sound occupies a third, the short pause a sixth, the second sound a sixth, and the long pause a third. Others aver that if we divide one entire action of the heart into four parts, the two first will be occupied by the first sound, the third by the second sound, and the fourth by the pause; all which proves very conclusively that the sounds and pauses run into each other and cannot be separated with any degree of accuracy. When so many causes exist it is exceedingly difficult, perhaps dangerous, to particularise. There are, however, many circumstances which induce me to believe that the susurrus, or sound produced by the opening and closing of the auricles and ventricles, and the rushing of the fluid blood against the valves and into the cavities and vessels of the heart, constitute the major factors, the opening and closing of the valves the minor.

The Dublin committee, appointed to investigate this matter, concluded that the first sound is produced either by the rapid passage of the blood over the irregular internal surface of the ventricles on its way towards the mouth of the arteries, or by the *bruit musculaire* (susurrus) of the ventricles, or probably by both of these causes. The London committee, appointed for a like purpose, came to similar conclusions. It found that the sound produced by the contraction (shortening) of the abdominal muscles, as heard through a flexible tube, resembles the systolic sound, and that the impulse of the heart against the chest in certain positions of the body intensified this sound. M. Marc D'Espine maintained that both the first and second sounds depend on muscular movements—the first sound upon the systole and the second upon the diastole of the ventricles. D'Espine, it will be observed, attributes sound both to the diastole or opening of the ventricles, and to the systole or closing of them, and in this I think he is perfectly correct—the opening and closing of the different parts of the heart, as I have endeavoured to show, being equally vital movements. That muscle invariably produces sound during its action is well known; and that a powerful compound muscle like the heart, with fibres interlacing in every direction, should, when closing and opening in hollow cavities such as the pericardium and thorax, produce audible and characteristic sounds, is what we would *à priori* expect. That sound may be produced by the impinging of fluids against animal tissues, or by the trituration of the particles of the fluid itself, can be proved by direct experiment. Valentin, for example, showed that if a portion of a horse's intestine be tied at one end, and moderately distended with water without any admixture of air, and a syringe containing water be fixed into the other end, by pressing the piston of the syringe down, and forcing in more water, the first sound is exactly imitated. When, on the other hand, the aortic or pulmonic valves are diseased, their surfaces roughened, and the apertures which they guard diminished, the character of the first sound is altered. Laennec and Dr. C. J. B. Williams regard the susurrus or noise produced by the contracting (closing) ventricles as the exclusive cause of the first sound; and the latter endeavoured to prove the point by cutting away the aorta and pulmonic vessels, and by placing the fingers in the auriculo-ventricular orifices, so as to exclude the blood. He found under these circumstances that the sound was still produced. I cannot, however, agree with Laennec and Dr. Williams when they state that the contraction (closure) of the ventricles is the sole cause; for, in cases of hypertrophy of the heart, the intensity of the first sound, instead of being increased, which it would be if solely due to the closing of the ventricles, is diminished. An attempt has been made to clear away this difficulty by saying that in such cases the susurrus of the superficial fibres alone is heard. That the first sound is in part due to the ventricular susurrus must, I think, be conceded, but that it is also due to the attrition of the blood against the great vessels and valves seems proved, 1st, by the experiment of Valentin with the piece of intestine already quoted; 2nd, by cases of anæmia where the character of the sound is changed, although the valves and vessels are healthy; and 3rd, by cases of diseased valves and vessels where the character of the sound is altered, the blood being normal. Rouanet, Billing, and Bryan referred the first sound to the rapid approximation of the auriculo-ventricular valves during the contraction (closure) of the ventricles. This, however, cannot be the sole cause; for, as I pointed out when explaining the action of these valves, their movements are not sudden but gradual and progressive. The auriculo-ventricular valves, in fact, move up and down like diaphragms as the systole proceeds. Thus they are elevated at the beginning of the systole, and drawn down or lowered towards the end of it. Bouillaud attributes the first sound partly to the closing of the auriculo-ventricular valves, and partly to the sudden opening of the pulmonic and aortic valves; while Mr. Carlisle refers it to the rush of blood along the pulmonary artery and aorta, occasioned by the contraction (closure) of the ventricles. The first sound, there are good grounds for believing, is referable, 1st, to the ventricular susurrus; 2nd, to the impinging of the blood against the auriculo-ventricular and semilunar valves; 3rd, to the closing

of the auriculo-ventricular valves and the opening of the semilunar ones; 4th, to the impulse of the heart; 5th, to the flow of blood into the auricles, caused by the closing of the cavæ and pulmonic veins; and 6th, to the rolling of the heart within the pericardium.

As Laennec attributed the first sound to the contraction (closure) of the ventricles, so in like manner he referred the second sound to the contraction (closure) of the auricles. The susurrus of the auricles no doubt contributes to this result, but the walls of the auricles are so thin that the share they take in the production of the sound must be trifling.

M. Rouanet, Billing, Bryan, Carlisle, Bouillaud, and Dr. Elliot have attributed the second sound principally to the regurgitation of the blood in the aorta and pulmonary artery, and the flapping together, closure, and tightening of the semilunar valves.[1]

Dr. C. J. B. Williams endeavoured to prove this by actual experiment on the ass. He passed a common dissecting hook through a segment of the pulmonic valve, with the effect of weakening the normal sound and producing a hissing one. He then passed a curved shoemaker's awl through a segment of the aortic valve, and the second sound ceased, a hissing sound being substituted. This author states that the second sound is loudest over the great vessels, and that it is suspended if these are artificially occluded and the auricles laid open. It must be admitted that the experiments referred to are not of a delicate or exact character. By opening the auricles those structures largely lose the power they possess of injecting the blood into the ventricular cavities: the characteristic sounds produced by the impinging of the blood against the auriculo-ventricular valves, chordæ tendineæ, carneæ columnæ, and musculi papillares being impaired and in some cases obliterated. By occluding the great vessels the sound resulting from the flow or oscillation of the blood within them, as apart from the effect produced on the valves, is destroyed. In healthy semilunar valves there is little, if any, regurgitation, the segments, from their being more or less in contact at the end of the systole, being closed by the slightest reflux, and with almost no noise. By transfixing by hooks two of the six segments composing the aortic and pulmonic semilunar valves, an abnormal element is introduced which renders the experiment of little value. The substitution of one sound for another proves nothing, and if the second sound is destroyed there is some fallacy, as only two of the six segments which were supposed to produce it were restrained. I am therefore disposed to put a different construction on the results obtained by Dr. Williams, and to attribute the second sound partly to the closure and susurrus of the auricles, but mainly to the rush of blood into the ventricular cavities, and against the auriculo-ventricular valves, chordæ tendineæ, carneæ columnæ, and musculi papillares. To this is to be added the flapping together of the semilunar valves, and the susurrus produced by the dilatation of the ventricles, venæ cavæ, and pulmonic veins.

As an illustration of the extreme difficulty experienced by investigators in determining the precise nature of the movements and sounds of the heart, I may cite the case of M. Groux, whom I had an opportunity of examining, and who exhibited in his person an almost unique example of congenital fissure of the sternum. Here we had the parts in the vicinity of the heart opened up as it were for inspection. M. Groux visited the principal schools on the Continent, in America, and Britain, and was examined by upwards of 2000 physicians, many of them eminently distinguished. The discrepancy of opinion is quite remarkable. In M. Groux's case, the fissure extended the whole length of the sternum, and presented a V-shaped appearance. In natural respiration, the fissure was depressed to variable depths, and had a transverse measurement at its upper boundary of one inch and a quarter; this increasing at the central part on a level with the third and fourth ribs to an inch and a half, and decreasing at the lower boundary of the fissure to a quarter of an inch. Through the action of the pectoral muscles, the hands being joined and pulling upon each other, the fissure could be dilated to the width of about two and a half inches. The fissure could be increased by forced expiration and decreased by forced inspiration. About the middle of the fissure, on a level with the fourth rib, a large pulsating tumour could be seen and felt. In a vertical line with the principal tumour were two smaller ones, the one above, which could be felt; the other below, which could, like the large one, be seen and felt. I analysed the movements of the pulsating tumours, with others interested in the heart, when M. Groux was in Edinburgh, and at first sight it appeared as if no great difficulty would be experienced in determining which parts of the heart produced the pulsations and sounds. A closer examination, however, revealed innumerable difficulties, all traceable to the circumstances already adverted to—namely, that the movements and sounds of the heart merge into each other by slow and sudden transitions. This case, simple as it appeared, has baffled the most expert physiologists and stethoscopists in all countries, so that instead of a few valuable facts we have a mass of conflicting evidence of comparatively little value. By some the large tumour has been supposed to be the aorta, by others the right auricle, by others the right ventricle, by others the infundibulum or conus arteriosus, and by others the arteria innominata. I have taken the pains to tabulate some of those opinions. Professor Hamernjce, (Prague), Dr. Wilhelm Reil (Halle), Professor Baumgärtner (Freiburg), Professor Forget (Strasburg), M. Jules Biclard,

[1] These valves are closed with considerable energy, partly because of the elasticity of the great vessels, and partly because of the sucking action exerted by the ventricles during the diastole.

M. Aran, M. Piorry, M. Pouchet (Rouen), Dr. Ernst (Zurich), Dr. F. W. Pavy (London), Dr. C. Radcliffe Hall (Torquay), and Dr. Robert D. Lyons (Dublin), thought the pulsating tumour was the right auricle; Sir James Paget, Dr. George Burrows, Dr. William Baly (London), and Dr. Traube (Berlin), that it was the right ventricle; Dr. Lionel S. Beale (London), Dr. John Hughes Bennett (Edinburgh), and Dr. Charles C. King (Galway), that it was the right auricle and ventricle; Dr. Lombard (Liege), and Dr. Francis Sibson (London), that it was the aorta and right auricle; M. Bouillaud and M. Marc d'Espine (Geneva), that it was the aorta; Professor Virchow, that it was the right ventricle and conus arteriosus; Dr. Carlisle (Belfast), that it was the ascending aorta and pulmonary artery; Dr. P. Redfern (Aberdeen), that it was the aorta, right auricle, and ventricle; Professor W. T. Gairdner (Glasgow), that it was the right auricular appendage, aorta, and right ventricle; and Dr. C. J. B. Williams (London), that it was the right auricle, ventricle, pulmonary artery, and aorta.

The accounts given by Drs. Pavy and Williams of M. Groux's pulsating tumour are very interesting. Dr. Pavy, who believed it to be the right auricle, states that it rises rapidly and suddenly, and instantaneously after falls with that peculiar thrill, wave, or vermicular movement, proceeding from above to below, which he pointed out as, at this period of the heart's action, running through the parietes of the auricle of the dog. Dr. Pavy, it will be observed, characterises the action of the auricle as progressive—the auricle contracting (closing) with a peculiar thrill, wave, or vermicular movement, proceeding from above to below. Dr. Williams, who thought the pulsation corresponded with the right auricle, states that the closing of the auricle immediately precedes the closing of the ventricle; the wave of motion, in slow pulsations, beginning with the auricle, and rapidly passing downwards to the ventricle.

In quick pulsations the closing of the auricle and the closing of the ventricle appear synchronous (mark how the auricular and ventricular movements glide into each other, and with what rapidity). Dr. Williams goes on to say that, by the aid of a small flexible ear-tube, with a narrow pectoral end, he heard *a distinct sound accompanying* the commencement of the auricular contraction or closure. It is faint, short, or flapping, and ends in the less abrupt and more distinct sound of the ventricular contraction or closure. When the stethoscope is placed over the ventricle the flapping sound of the auricle is not heard, but the vessel swells or rolls out its peculiar sound, till it ends with the sharp clack of the diastolic or valvular sound. Dr. Williams concludes from this that each movement of the heart has its proper sound, and that the reason why the auricular sound is not usually heard is, that it is too faint to pass through the intervening lung. Dr. Radcliffe Hall thought there were three distinct degrees of distance of sound, indicating as many distinct sources; the sound in the presumed auricle being far more superficial and bell-like than that produced by the aorta above, or the right ventricle below. Dr. Williams thought he made out two distinct valvular sounds. By placing the stethoscope over the aorta, he detected a simple sound (lubb-dup); but when he placed it partly over the aorta, and partly over the pulmonary artery, he obtained a double sound (lubb-darrup) from the valves not closing at exactly the same instant. This want of synchronism in the action of the aortic and pulmonic valves occurs principally in disease; but it is also found in health, and tends to show that the closure of the right and left ventricles is progressive, which is just what we would expect when we remember that muscular movements originate in the sarcous elements and diffuse themselves.

The nerves of the heart, from the influence they exert upon its movements, come next to be considered.

THE GANGLIA AND NERVES OF THE HEART, AND THEIR CONNECTION WITH THE CEREBRO-SPINAL AND SYMPATHETIC SYSTEMS IN MAMMALIA.

The movements of the heart, and the circulation generally, are directly and indirectly influenced by the nervous system. This is sufficiently proved by the division and irritation of such nerves as send filaments to the organ; these experiments being attended in some cases with a *slowing* of the heart's action, and in others by *quickening* action. Similar results are obtained by the administration of certain active substances, some of which paralyse and others stimulate the nerves conducting to and from the heart. The movements of the heart, as is well known, cannot be controlled by efforts of the will; they are nevertheless influenced by certain mental conditions, sudden joy being calculated to render the movements of the organ tumultuous; and protracted grief and watching to impede rather than quicken them. The intimate connection between the head and heart induced the ancients to regard the heart as the seat of the affections—a view which is adopted in popular parlance.

The nerves of the heart are derived from two sources, namely, the pneumogastric (nervus vagus, par vagum) and the sympathetic (nerve of organic life, Bichat).

The pneumogastric and sympathetic nerves are compound in their nature; that is, they contain afferent or sensory and efferent or motor nerve-filaments.

The pneumogastric nerve has its origin within the cranium, while the sympathetic lies outside the spinal cord.

Both, however, are connected by nerve-filaments to each other and to the cranial and spinal nerves; an arrangement which in part accounts for the involuntary rhythmic movements of the heart, and for the influence exerted upon those movements by certain mental states. Considerable difference of opinion exists as to the exact nature of the so-called *sympathetic* and *cerebro-spinal nerves*. There are two leading views :—" According to the one, which is of old date, but which has lately been revived and ably advocated by Valentin, the sympathetic nerve is a mere dependency, offset, or embranchment of the cerebro-spinal system of nerves, containing no fibres but such as centre in the brain and cord, although it is held that these fibres are modified in their motor and sensory properties, in passing through the ganglia in their way to and from the viscera and involuntary organs. According to the other, the sympathetic nerve (commonly so called) not only contains fibres derived from the brain and cord, but also proper or intrinsic fibres which take their rise in the ganglia; and in its communications with the spinal and cranial nerves, not only receives from these nerves cerebro-spinal fibres, but imparts to them a share of its own proper ganglionic fibres, to be incorporated in their branches and distributed peripherally with them. Therefore, according to this latter view, the sympathetic nerve, commonly so called, though not a mere offset of the cerebro-spinal nerves, yet receiving as it does a share of their fibres, is not wholly independent, and for a like reason the cerebro-spinal nerves (as commonly understood) cannot be considered as constituted independently of the sympathetic; in short, both the cerebro-spinal and sympathetic are mixed nerves; that is, the branches of either system consist of two sets of fibres of different and independent origin, one connected centrally with the brain and cord, the other with the ganglia."

In order to comprehend the relation existing between the heart and the cerebro-spinal and sympathetic systems of nerves, it will be necessary to speak first of the pneumogastric and those branches which it sends to the heart; second, of such parts of the sympathetic as supply filaments to the organ; and third, of those nervous extensions which connect the pneumogastric, sympathetic, and cerebro-spinal nerves together. This done, we shall then be in a position to describe the meshes or plexuses formed by the splitting up and mingling of the several nerves referred to at the base of the heart, their distribution on the surface and in the substance of the organ, and the nature of the ganglionic enlargements which characterise the cardiac nerve reticulations.

In man the pneumogastric nerve springs from that part of the cerebro-spinal axis known as the *medulla oblongata*. It issues from the jugular foramen, an aperture at the base of the skull, and courses down the neck and chest to supply filaments to the organs of voice, respiration, the alimentary canal as far as the stomach, and to the heart. It is the longest of the cranial nerves, and displays two ganglionic enlargements or swellings, the one designated the *ganglion of the root* of the pneumogastric, situated within the jugular foramen; the other the *ganglion of the trunk* of the pneumogastric, situated half an inch or so below that opening.

The upper ganglion, namely, that of the root, is somewhat spherical in shape, two lines in diameter, and of a grayish colour; the lower ganglion, namely, that of the trunk, being of a flattened cylindrical form, ten lines in length, two in breadth, and reddish in colour. In the neck the ganglion of the root (upper ganglion) is connected by nerve-filaments with the facial, the glosso-pharyngeal, spinal-accessory, and sympathetic nerves; the ganglion of the trunk (lower ganglion) being connected in the same region with the hypo-glossal, spinal, and sympathetic nerves.

In the thorax the branches of the right and left pneumogastric nerves pursue somewhat different courses: the recurrent laryngeal branch on the right side curving backwards and upwards round the first part of the right subclavian artery, the recurrent laryngeal branch on the left side curving backwards and upwards round the arch of the aorta. The recurrent nerves send branches to the so-called deep cardiac plexus, placed behind the pulmonary artery and aorta. The pneumogastric nerves (right and left) supply branches to the ear, pharynx, larynx, lungs, the œsophagus, stomach, spleen, liver, and other organs. They also furnish two sets of nerves to the heart—a cervical and thoracic set: with these alone we have to deal in the present instance.

§ 169. **The cervical cardiac branches** are given off by the pneumogastric at the upper and lower portions of the neck. The upper branches, which unite with the cardiac nerves of the sympathetic, are few in number, and small. There is only one lower branch. This, in the left side, crosses the arch of the aorta, and terminates in what is called the superficial cardiac plexus, situated in front of the pulmonary artery and aorta. On the right side it unites with one of the cardiac nerves and takes part in the formation of the deep cardiac plexus, located, as explained, behind the pulmonary artery and aorta. The nerves constituting the superficial and deep cardiac plexuses are continuous with each other, and completely envelop the great vessels (pulmonary artery and aorta) at their origins.

§ 170. **The thoracic cardiac branches** on the right side proceed from the first part of the right recurrent laryngeal nerve, and the trunk of the right pneumogastric nerve, where it is in contact with the trachea; those on the left side proceeding from the left recurrent laryngeal nerve. The thoracic branches assist in the formation of the deep cardiac plexus. The pneumogastric nerves, as will be seen from the foregoing account, are connected with the cranial nerves issuing from the head, with the spinal nerves issuing from the spinal cord, and with the sympathetic nerves lying in front of the spinal cord.

The sympathetic system supplies the major portion of the nerves to the heart. It also sends branches to the lungs and stomach, the upper part of the alimentary canal, the bladder, uterus, and the coats of the blood-vessels.

The nerves of the sympathetic system consist of a complicated series of ganglia, cords, and plexuses; the ganglia and the cords which extend between them being arranged in a double row on either side of the spine, and corresponding for the most part in situation with the bodies of the cervical, dorsal, and lumbar vertebræ. There are, however, only three ganglionic enlargements in the neck in man to seven vertebræ, there being even fewer in some of the lower animals. This state of matters is probably due to the ganglia in the neck having at some period approximated and coalesced.

The sympathetic cervical ganglia in man are designated superior, middle, and inferior, from their respective positions; one being placed at the base of the skull, a second at the root of the neck, and the third above the head of the first rib. They are united to the spinal nerves in their immediate vicinity by short cords composed of white and gray matter; the white matter, it is believed, proceeding from the spinal nerves to the ganglia, the gray matter from the ganglia to the spinal nerves. The cords extending between the ganglia are similarly constituted.

§ 171. **The superior cervical ganglia** are connected with certain of the cranial nerves as well as with the spinal nerves. Thus small twigs unite the superior cervical ganglion with the first four spinal nerves, with the first and second ganglia of the pneumogastric, with the ninth cranial nerve, and with the petrosal ganglion of the glosso-pharyngeal nerve. Besides the branches which it gives off to the spinal and cranial nerves, the superior cervical ganglion supplies branches to the pharynx, blood-vessels, and heart.

§ 172. **The middle and inferior cervical ganglia** likewise supply branches to the heart.

The branches given off by the three cervical ganglia of the sympathetic are named respectively the *superior, middle*, and *inferior cardiac branches*.

The cardiac branches vary in size, and also in their distribution on the right and left sides.

§ 173. **The upper cardiac nerve** of the right side proceeds from two or more branches of the superior cervical ganglion, with occasionally a branch from the main cord which connects the superior and middle cervical ganglia. In its passage down the neck it is joined by filaments from the external laryngeal and the trunk of the pneumogastric, and as it enters the chest it unites with the recurrent laryngeal. It contributes to the formation of the deep cardiac plexus. On the left side the upper cardiac nerve runs parallel with the left carotid artery until it reaches the arch of the aorta, where it breaks up to assist in forming the superficial or deep cardiac plexus according as it passes in front of or behind that vessel.

§ 174. **The middle cardiac nerve** on the right side communicates with the upper cardiac nerve and the recurrent branch of the pneumogastric. It sends filaments to the deep cardiac plexus. The middle cardiac nerve on the left side also sends branches to the deep plexus.

§ 175. **The inferior cardiac nerve** on the right side communicates with the middle cardiac and recurrent laryngeal nerves, and terminates in the cardiac plexus at the arch of the aorta. On the left side it unites with the middle cardiac nerve and ends in the deep cardiac plexus.

The superficial and deep cardiac plexuses, as already stated, are continuous with each other. They receive filaments from the recurrent, lower cervical, and thoracic branches of the right and left pneumogastric trunks; and from the superior, middle, and inferior cardiac nerves of the right and left sympathetic trunks. They envelop the origins of the pulmonary artery and aorta in a meshwork, after which they resolve themselves on the anterior and posterior surfaces of the heart.

Thus the superficial cardiac plexus sends branches to the anterior and right coronary arteries, and to the anterior portions of the right and left auricles and ventricles; the deep cardiac plexus sending branches to the coronary sinus and left coronary artery, and the posterior surface of the right and left auricles and ventricles. A few of the branches forming the superficial cardiac plexus pass backwards and appear on the posterior surface of the heart; a certain number of the branches from the deep cardiac plexus passing forwards to appear on the anterior surface of the heart. It is quite correct to say that the surface and substance of the auricles and ventricles are enveloped in a more or less uniform plexus. The superficial and deep cardiac plexuses and their prolongations on the surface and in the substance of the heart display numerous ganglionic enlargements, to be described presently.

The branches supplied by the pneumogastric and sympathetic nerves to the heart on the right side of the human subject are represented at Fig. 214. This figure also shows the interlacing of the nervous filaments which forms the various plexuses described, as well as the ganglionic enlargements, which are a distinguishing feature of the plexuses.

In the lower animals the relations of the pneumogastric, sympathetic, and cardiac nerves are less complicated than in man, and if I could have afforded space it would have been interesting to trace them. I have dissected them in the cat, rabbit, and calf, and find that, while the branches supplied by the pneumogastric nerves are tolerably constant, those furnished by the ganglia of the sympathetic and the ganglia themselves vary. Thus, in the cat,

according to my dissections, only four ganglia (two on the right side and two on the left) send branches to the heart; whereas in the rabbit, the ganglia supplying branches are increased to six, and in the calf to eight. The number of nerves found on the surface and in the substance of the calf's heart is greater than in any heart which I have examined—a circumstance which has induced me to select it for description.[1]

§ 176. Nerve-plexuses formed on the Roots of the Pulmonary Artery and Aorta in the Calf.

These plexuses are virtually three in number.

First, that found on the ascending aorta (Fig. 215, *b*, p. 573) and superior cava (*i*), composed of branches from the superior or first dorsal ganglion of either side, and from the pneumogastric of the right side.

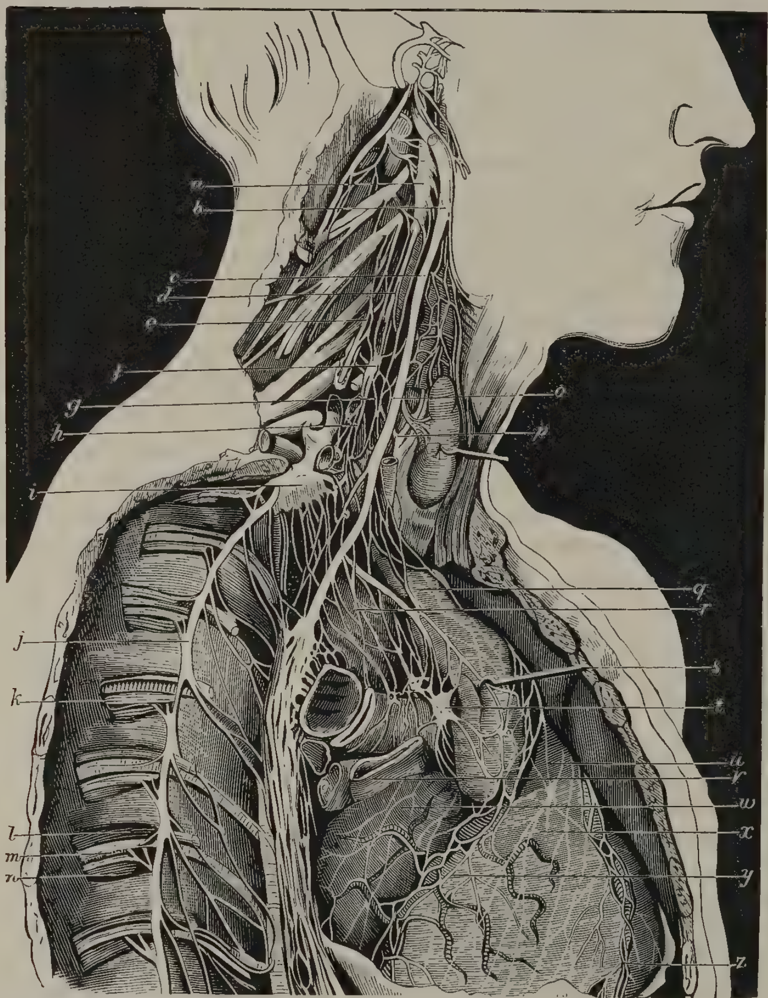


FIG. 214.—Shows the nerve-filaments supplied to the heart by the pneumogastric and sympathetic nerves on the right side in man (after Hirschfeld and Leveillé). *c*, Trunk of right pneumogastric nerve in neck; *b*, ganglion of trunk of right pneumogastric nerve; *d*, trunk of great sympathetic nerve in neck; *h*, trunk of great sympathetic nerve at root of neck; *j*, trunk of great sympathetic nerve in thorax; *a*, superior cervical ganglion of sympathetic nerve; *f*, middle cervical ganglion of sympathetic; *i*, inferior cervical ganglion of sympathetic; *e*, superior cardiac nerve; *g*, middle cardiac nerve; *o*, nerve from middle cervical ganglion of sympathetic proceeding to right recurrent laryngeal nerve (*p*); *k*, intercostal nerves; *l*, intercostal vein; *m*, intercostal artery furnished with nerve from ganglion of sympathetic; *n*, intercostal nerve receiving branch from trunk of sympathetic; *q*, innominate artery; *r*, trachea with nerves proceeding to deep cardiac plexus; *s*, arch of aorta with nerve-plexus, dragged forward by a hook; *t*, posterior or deep cardiac plexus with ganglion; *u*, pulmonary artery with nerve-plexus; *v*, superior cava cut across; *w*, right auricle with nerve-plexus; *x*, right ventricle with nerve-plexus; *y*, plexus of nerves investing the vessels occupying the horizontal, or right auriculo-ventricular groove; *z*, a similar plexus investing the vessels occupying the vertical ventricular groove anteriorly.

Secondly, that situated on the pulmonary artery (*a*), and between that vessel and the left auricle (*d*), composed of branches from the first dorsal ganglion of the left side, left pneumogastric, and left recurrent laryngeal.

Thirdly, that formed on the coronary sinus (Fig. 216, *j*, *r*, p. 573), composed almost exclusively of branches from the second and third dorsal ganglia of the sympathetic of the left side. The aortic plexus supplies branches to that

[1] My cardiac nerve dissections, fifty in number, are deposited in the Anatomical Museum of the University of Edinburgh, where they may be examined. They embrace specimens of the cardiac nerves of man, the horse, calf, sheep, cat, rabbit, &c. For descriptions of the dissections *vide* Gold-Medal Inaugural Dissertation "On the Ganglia and Nerves of the Heart, and their Connection with the Cerebro-spinal and Sympathetic Systems in Mammalia," deposited in the Library of the University of Edinburgh in 1861.

surface of the right auricle (Fig. 215, *c*) directed towards the aorta, and likewise to the right ventricle (*e*) and right coronary vessels (Fig. 218, *h*, p. 575). These plexuses, as well as the distribution of the nerves on the anterior and posterior surfaces of the heart generally, are seen at Figs. 215 and 216.

Nerve-plexus formed on the Anterior Coronary Vessels of the Calf.—Those branches of the first dorsal ganglion which do not expend themselves on the ascending aorta, descend behind the pulmonary artery to supply branches to the anterior aspect of the left auricle (Fig. 215, *d*). They then appear between the left auricle and pulmonary artery, and form an elaborate plexus on the anterior coronary vessels (*g*) and the anterior surface of the ventricles generally (*e*, *f*). This plexus is well seen in the human heart (Fig. 214, p. 572) and that of the horse (Fig. 217, A, *a*, *b*, *c*, *d*, *e*, p. 574), and if the nerves composing it be carefully examined they will be found to display a great number of ganglionic enlargements and spindle-shaped swellings, particularly where they cross vessels, and where they split up to change their direction and enter the substance of the heart. Some of these ganglia are of large size, and communicate with as many as four, six, and eight nerve-filaments.

§ 177. Nerve-plexus formed on the Coronary Sinus of the Calf.

This plexus, which is either altogether omitted or very imperfectly represented in works on the nerves of the heart, is composed almost exclusively of branches from the second and third dorsal ganglia of the sympathetic on the left side (Fig. 216, *j*, *r*, and Fig. 217, C, *j*, *r*, p. 574). It affords the chief supply to the left ventricle, which it occasionally envelops in a beautiful network of delicate nerves, as shown at *f* of Figs. 218, and 219, p. 575. The nerves forming the coronary plexus are in many cases so fragile that it is impossible to preserve them. In one specimen, which I showed Professor Goodsir, the sinus was completely covered with nerve-filaments, so that it would have been difficult to insert the head of a pin between them. In other specimens (Fig. 216, *r*, Fig. 217, C, *r*, p. 574), the nerves are stronger and not so plentiful, the meshes or spaces between the nerve-filaments being somewhat greater. In every case the nerves on the coronary sinus and posterior surface of the heart display a vast number of ganglionic enlargements and spindle-shaped swellings, some of them so large as readily to be detected by the naked eye; others requiring the aid of a pocket lens and a good light. The ganglia vary in shape as well as size. Thus in one of my dissections a stellate-shaped ganglion with seven branches is found on the coronary sinus; another with five branches is seen in a second dissection on the left coronary artery posteriorly; a large triangular ganglion with numerous nerve filaments being detected in a third, where the coronary sinus receives the left coronary vein. In a fourth, several irregularly-shaped ganglionic masses of large size occupy the coronary sinus. In a fifth, a triangular-shaped ganglion is found on the left coronary artery below the sinus; while in a sixth a well-marked ganglionic enlargement, situated on the sinus and having five branches, is readily recognised.

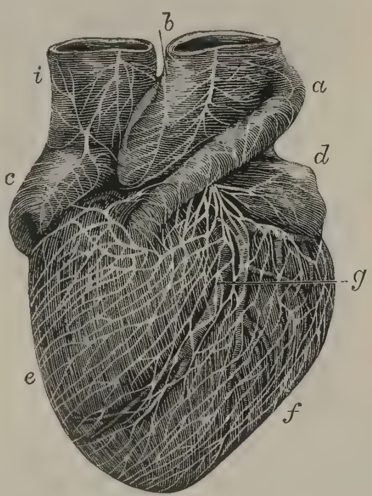


FIG. 215.

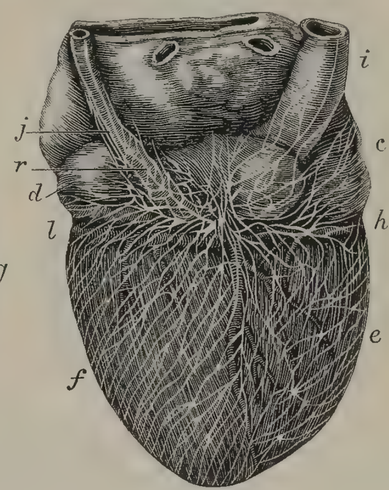


FIG. 216.

FIG. 215.—Nerves and ganglia on anterior surface of calf's heart. *a*, *b*, Pulmonary artery and aorta with nerve-plexuses and ganglia; *i*, descending cava with nerve-plexus and ganglia; *c*, right auricle; *d*, left auricle; *e*, nerves and ganglia distributed on right side of heart; *f*, nerves and ganglia distributed on left side of heart; *g*, anterior coronary vessels covered with nerve-plexuses and ganglia. From photograph and dissection by the Author, 1860.

FIG. 216.—Nerves and ganglia on posterior surface of calf's heart. *i*, Descending cava; *c*, nerves and ganglia on right auricle; *d*, nerves and ganglia on left auricle; *e*, nerves and ganglia on right ventricle; *f*, nerves and ganglia on left ventricle; *j*, great nerve-plexus and ganglia covering coronary sinus (*r*) and extending itself on the right (*h*), left (*l*), and posterior coronary vessels, and the right (*e*) and left (*f*) ventricles generally. The ganglia in this case are very numerous, particularly on the coronary sinus (*r*). From photograph and dissection by the Author, 1860.

The cardiac plexuses have been more or less accurately represented by Scarpa, Remak, Swan, Lee, and others.

§ 178. Distribution of the Nerves on the Surface and in the Substance of the Auricles of the Heart of the Calf.

The nerves supplied to the right auricle are as a rule very delicate, and proceed from the right pneumogastric, from the first dorsal ganglion of the sympathetic on the right side, and from the coronary plexus.

Those supplied to the left auricle are derived principally from the coronary plexus, some offsets being sent from

the left pneumogastric, and the first dorsal ganglion of the sympathetic on the left side. The nerves, on reaching the surface of the auricles, break up and spread out to form a nervous reticulation or network. Ganglia may be detected in numbers where the nerves split up, where they encounter vessels, and where they dip into the substance of the auricles. Of the nerves which enter the substance of the auricles not a few pass through the auricular walls. The nerves supplied to the auricles are not quite so numerous as those supplied to the ventricles.

§ 179. Distribution of the Nerves on the Surface and in the Substance of the Ventricles of the Heart of the Horse and Calf.

The nerves on the surface of the ventricles, if allowance be made for their breaking up slightly to form meshes, follow a common course; that is, they run in spiral lines from right to left downwards. The direction pursued by the nerves is the opposite of that pursued by the muscular fibres; in other words, the muscular fibres form left-handed spirals, whereas the nerves form right-handed spirals. I mention this, because although it has been noted that the nerves cross the muscular fibres obliquely from base to apex, no allusion is made to the complete spirals formed by them, particularly as they near the apex. These points are illustrated at Figs. 215, 216, p. 573, 217, B, 218 and 219, p. 575.

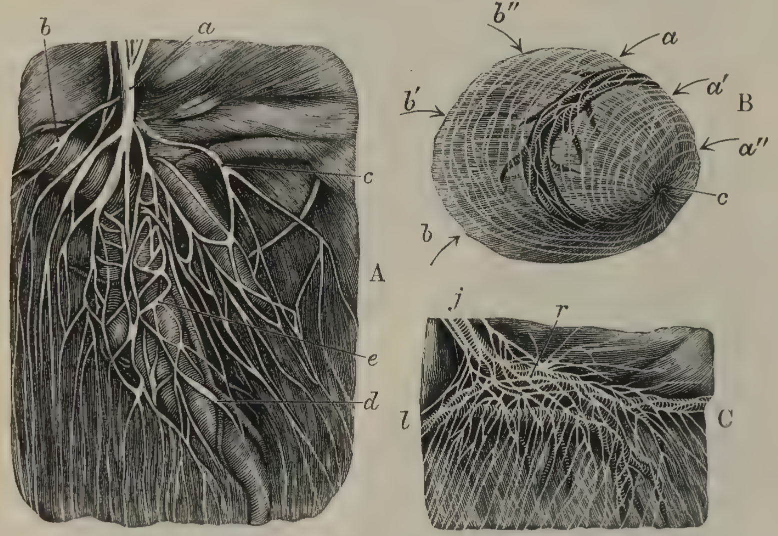


Fig. 217.—A. Nerves and ganglia on horse's heart. *a*, Large quadrangular ganglion communicating with five branches. Three of these branches form ampullæ or spindle-shaped swellings where they cross the coronary artery. Similar swellings are observed where the nerves cross the vessels occupying the anterior ventricular groove (*d*, *e*).

B. Apex of left ventricle of calf's heart. Shows that the muscular fibres of the ventricle pursue a spiral direction from left to right downwards (*b*); the nerves pursuing a spiral direction from right to left downwards (*a*), and always crossing the muscular fibres at nearly right angles. Several ganglia are to be observed on the nerves as they approach the apex (*c*).

C. Nerve-plexus and ganglia on coronary sinus (*j*) and base of left ventricle (*l*) of calf's heart. The ganglia (*r*) in this situation are for the most part quadrangular and triangular in shape, and stand boldly out. They consist of a superficial and a deep set. From photographs and dissections by the Author, 1860.

The nerves, from the fact of their crossing the muscular fibres and blood-vessels at a great many different points, are in a position to stimulate or to intercept stimulus, so that one can readily understand how the nerves regulate not only the movements but also the nourishment of the ventricles.[1] The blood-vessels, as is well known, occupy the anterior and posterior coronary grooves; that is, the *sulci* or furrows which separate the right and left ventricles from each other. They also occupy the transverse grooves which separate the right and left auricles from the right and left ventricles. As the manner in which the coronary vessels break up to nourish the heart is not well understood, I may state that the branches are given off from the main trunks very obliquely, and in such a manner that they cross the muscular fibres of the right and left ventricles at nearly right angles. When they have proceeded a certain distance they dip into the substance of the ventricles and branch or bifurcate; the smallest branches penetrating the muscular walls in a direction from without inwards. That the nerves bear an important relation to the blood-vessels will appear from this. The nerves invariably form plexuses on the vessels, and the ganglionic enlargements and spindle-shaped swellings are always most numerous where the nerves come in contact with or cross them. The nerves occasionally even swerve from their original course to intersect and accompany certain vessels. They likewise form nervous rings or loops on such vessels as are embedded in the substance of the ventricles, but accidentally rise to the surface. In a word, the nerves not only constantly intersect the vessels, but in many instances send off fine filaments to run in the direction of the length of the vessels, a triangular enlargement or ganglion being found where the nerves separate. As a rule the nerves are thickened and flattened where they cross the vessels, the nerves at these points presenting a spindle-shaped characteristic appearance (Fig. 217, A, *a*, *b*, *c*, *d*, *e*; and Fig. 219, *n*, p. 575). These ampullæ or swellings on the nerves where they cross the vessels were described by Lee as ganglia, although on what grounds he does not state. He is quite correct in so regarding them, as I find they contain numerous unipolar with a few bipolar

[1] While the nerves regulate, within limits, the movements of the heart, they do not cause them. The movements are inherent and fundamental.

nerve-cells. Similar remarks may be made regarding the stellate-shaped ganglionic enlargements everywhere perceptible on the surface of the heart. To these allusion is made further on.

§ 180. Distribution of the Nerves on the Right and Left Ventricles.

As a proof that some purpose is served by the spiral distribution of the nerves on the ventricles, I may refer to the arrangement on the right ventricle (Fig. 218). This ventricle, it will be remembered, is supplied by the nerve-plexus formed on the aorta, and between that vessel and the pulmonary artery (*b*). As, however, the plexus in question is situated behind the pulmonary artery and the *infundibulum* or *conus arteriosus*, it follows that if the nerves were at once to proceed on their downward course, not only would the *infundibulum* be left destitute of nerves, but their direction would nearly correspond with that of the muscular fibres.[1] In order, therefore, to enable the nerves to run in a contrary direction to that of the muscular fibres, they at first proceed in a forward direction so as to cross the *infundibulum* and supply the vessels thereon, after which (and mark this) they suddenly bend upon themselves at nearly right angles in order fairly to intersect the muscular fibres in spiral lines in a direction from right to left downwards.

The points to be more particularly attended to in the distribution of the nerves on the right ventricle are the following :—They are derived from the plexus which invests the aorta, and extends between that vessel and the pulmonary artery. They receive, as was formerly stated, a few branches from the plexus on the anterior coronary vessels. They run in a spiral direction from before backwards and from right to left; a course the opposite of that pursued by the muscular fibres and the branches of the cardiac vessels. Generally, they split up from time to time, the branches maintaining a certain parallelism and becoming finer and finer as they reach the posterior surface of the ventricle (Fig. 218, *e*). Occasionally the nerves coalesce or run together, and under these circumstances there is a marked increase of nerve-substance at the point of junction. This is particularly the case in the large ganglion represented at *k* of Fig. 218. When the nerves reach the posterior surface of the ventricle (*e*), they unite with others from the plexus on the coronary sinus to form stellate-shaped expansions or ganglia—well seen at *e* of Fig. 216, p. 573. The expansions referred to display, on microscopic examination, numerous unipolar and bipolar nerve-cells. The plexus formed on the right coronary artery (Fig. 218, *h*), when examined with a lens in a good light, is found to be very complex. The nerves on the right ventricle (Figs. 216, p. 573, and 218 *e*) are fewer in number than those on the left ventricle (Fig. 219, *f*). Posteriorly, there is usually a part of the right ventricle comparatively unprovided for, where the terminal nerve-filaments of the right ventricle unite with similar terminal nerve-filaments from the plexus on the coronary sinus.

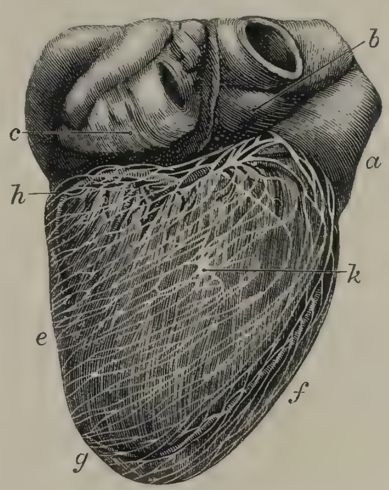


FIG. 218.

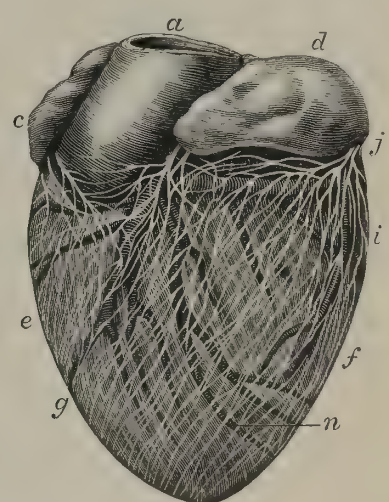


FIG. 219.

FIG. 218.—Nerves and ganglia on right ventricle of calf's heart. *a*, Pulmonary artery; *b*, aorta; *c*, right auricle; *h*, plexus of nerves on right coronary vessels; *e*, nerves and ganglia on right ventricle; *f*, left ventricle; *g*, anterior coronary vessels; *k*, large ganglion with numerous nerves proceeding to and from it. A large number of similar but smaller and more delicate ganglia are seen on a close examination. From photograph and dissection by the Author, 1860.

FIG. 219.—Nerves and ganglia on left ventricle of calf's heart. *a*, Pulmonary artery; *c*, right auricle; *d*, left auricle; *e*, ganglia and nerves on right ventricle; *f*, ganglia and nerves on left ventricle; *j*, ganglia and nerves on coronary sinus, which extends to left coronary vessel (*i*) and left ventricle (*f*), both of which it envelops in a beautiful network of nerves and ganglia. The ganglia are well seen on the left coronary artery (*i*) and one of the branches (*n*) of the anterior coronary artery. The swellings or enlargements of the nerves as they cross the vessels are represented more especially at *n*, but they are observed wherever vessels occur. From photograph and dissection by the Author, 1860.

Distribution of the Nerves on the Left Ventricle.—This ventricle derives its nervous supply almost exclusively from the plexus situated on the coronary sinus (Fig. 216, *j*, *r*, p. 573; Fig. 217, C, *j*, *r*; Fig. 219, *j*). It exhibits still more clearly than the right, the spiral course pursued by the nerves. As a rule, the nerves on the posterior surface of the left ventricle proceed in almost parallel lines (Fig. 216, *f*, p. 573), subdividing and becoming more attenuated as they near the apex. On the lateral and anterior aspect of the ventricle the arrangement is more irregular—that is, it assumes to a certain extent the plexiform character (Fig. 219, *f*, *g*). In one of my

[1] The infundibulum or *conus arteriosus* corresponds to the conical-shaped portion of the right ventricle from which the pulmonary artery springs.

dissections it is altogether plexiform, and the nerves, by alternately dividing, subdividing, and reuniting, produce a beautiful network of nerves which envelops the ventricle from base to apex. In examining this network I find that sometimes as many as three branches unite when crossing a vessel, after which they separate and reunite when another vessel is to be crossed (*n*). The plexus formed on the left coronary vessels (Fig. 216, *l*, p. 573) is an extension of that formed on the sinus (*j*, *r*). It is very intricate, and when patiently examined with a lens in a good light numerous ganglia and spindle-shaped enlargements are discovered (Fig. 217, C, p. 574). The spindle-shaped enlargements occurring on the general surface of the left ventricle are usually met with where the nerves cross the vessels, as was correctly described and figured by Lee. Lee, however, it appears to me, has slightly exaggerated the number and size of the enlargements, as well as the number of branches with which they communicate. The enlargements in many cases are apparently produced by a mere flattening of the nerves on the projecting rounded surface of the vessels (Fig. 219, *n*, p. 575). The appearance of the enlargements (they are spindle-shaped) suggests this idea. I am, however, satisfied that there is an actual increase of nerve-substance ; a view favoured by the fact that they contain a large number of nerve-cells, and not a few of them give off one or more delicate nerve-filaments to the vessels they cross. In this respect they resemble the typical stellate-shaped ganglia found on the coronary sinus (Fig. 216, *j*, *r*, p. 573 ; and Fig. 217, C, *j*, *r*, p. 574). In the heart of a camel which I had the good fortune to obtain through the kindness of Professor Goodsir, the increase of nerve-substance was very marked, the enlargements in this instance having a somewhat quadrangular shape, and sending branches to the vessels and other nerves.

The number of nerves which dip into the substance of the left ventricle is considerable. Large and small branches disappear separately or together without apparently following any order. Generally speaking, they take advantage of a vessel entering the substance and accompany it, or they seek one of the openings occurring between the muscular fasciculi. In a dissection which I made of the horse's heart, three branches were observed to enter the posterior wall of the left ventricle within a few lines of each other. The distribution of the nerves in the substance of the right ventricle is similar in all respects to that described in the left. The arrangement of the nerves in the substance of the heart is essentially the same as on its surface. Thus, the nerves run slantingly, and so come in contact with the vessels and muscular fibres. Ganglia are found on the deep nerves as on the more superficial ones, although not to the same extent.

§ 181. Distribution of the Nerves in the Human Heart.

The number of nerves is slightly fewer in the human heart (Fig. 214, p. 572) than in that of the calf and some of the lower animals. The nerves are also more delicate, the aggregate of the nerve-filaments as compared with the aggregate of the muscular fibres being less. The distribution and arrangement are as nearly as may be identical with that described in the calf. It is somewhat difficult to get a good view of the nerves of the human heart, partly from the greatly thickened condition of the exocardium or outer covering of the heart, and partly from the excessive quantity of fat which usually invests it, particularly in the vertical and horizontal coronary grooves. By a diligent search, extending over several years, I have secured some very fine specimens, the best of which have been obtained from young or emaciated patients, or those who died from dropsy, in which case an excess of pericardial fluid had softened and rendered the exocardium more or less transparent. The nervous supply to the posterior surface of the human heart is, comparatively speaking, very scanty ; a deficiency observed in the hearts of many of the lower animals, though not to the same extent. As regards the actual number of nerves on the ventricles of the human heart, authorities differ. According to Scarpa and what I myself have seen, the nerves are fewer and more delicate than in the lower animals. Of this I think there can be little doubt, as I have examined some hundreds of human hearts more or less carefully. Lee nevertheless affirms that the nerves of the human heart are quite as numerous as those of the heart of the heifer. He corroborates his statement by drawings of the nerves as seen on the heart of a child nine years of age, and on the adult human heart hypertrophied.[1] Lee's preparations are deposited in the Museum of St. George's Hospital, London, and I am disposed to believe, from an inspection of them, that he has to some extent been misled by his not having injected the minute cardiac vessels, and by his manner of dissection (he teases the nerves out by the aid of needles—a procedure which displaces the nerves, and causes shreds of the exocardium or fibrous membrane investing the heart greatly to resemble nerves). In my own dissections, deposited in the Anatomical Museum of the University of Edinburgh, I have endeavoured to avoid this source of error by careful injections of the cardiac arteries and veins with two colours, and by dissecting everything away from the nerves, without dragging or pulling upon the nerves themselves. The nerves in my dissections are consequently *in situ*, and their relations to the cardiac vessels and muscular fibres undisturbed. The ganglionic

[1] Dr. Robert Lee, "On the Ganglia and Nerves of the Heart," Plates 1 and 5. (*Phil. Trans.*, 1849.)

enlargements found on the nerves of the human heart have been partially figured by Scarpa and more fully by Lee. I have shown them at Fig. 214, p. 572. They are not so distinct as those found on the nerves of the heart of the calf, neither are they so numerous ; nevertheless, they are sufficiently numerous and well marked to attract attention.

§ 182. Nerves and Ganglia of the Human Heart.

In only one instance have I found the nerves of the human heart in great profusion. In that case the heart was hypertrophied, and belonged to a tall, athletic, emaciated individual, aged sixty-two.

His nervous system was highly developed—the nerve-plexuses of the thoracic and abdominal viscera, which I carefully examined, being very prominent. I am particular in mentioning these facts, because the nerves on and in the heart in question were unusually large ; the supply to the human heart being, as a rule, comparatively scanty. On examining the heart after its blood-vessels were injected with coloured size, and before it was put in spirit, the nerves, on account of the transparency of the exocardium, were seen to great advantage. They were found to be very numerous and very fully developed, especially on different parts of the anterior surface. I could detect two distinct systems, namely, a superficial and very delicate system the sheaths of which were incorporated with the exocardium, and a deeper and stronger system which ramified on the superficial and deep vessels in the substance of the heart. I call attention to this fact because, in attempting to strip off the exocardium, a large number of very delicate nerve-fibres were removed with it. In order to see these delicate nerve-fibres to advantage it is advisable to examine the heart in the fresh state in the sunlight and with the aid of a dissecting lens. I say, in the fresh state, because if the heart is put in spirit, even for a short period, the nerves become blanched and shrink, and the muscular substance of the heart losing its dark red colour, the dark background which renders them prominent is removed. The sunlight is necessary because of their extreme delicacy. The nerves in the human heart in all respects resemble those found on and in the hearts of the lower animals, as, for example, the sheep, calf, pig, seal, horse, &c. Thus on the anterior surface of the heart, where they are most numerous, they form a rich plexus or net-work ; the larger trunks which issue from between the root of the pulmonary artery and left auricular appendage following the track of the anterior coronary artery and vein, which they cross and re-cross in divers directions above and beneath ; the smaller following the courses of the smaller blood-vessels, which they embrace in a similar fashion. Running between the two sets of nerves alluded to are still finer ones which cross the capillaries in all directions, and, as this arrangement obtains also in the substance of the heart, there is no part of the organ which is not minutely and plentifully supplied with nerve twigs.

Where the nerves, whatever their size, cross the blood-vessels on the surface and in the substance of the heart they form flattened swellings, which I have ascertained by microscopic examination are crowded with nerve-cells. Triangular enlargements also are found where nerves meet or bifurcate, and in these, likewise, nerve-cells can be detected. The nerve-cells are unipolar and bipolar, the former predominating. The swellings are true ganglia, and not, as some suppose, mere thickenings and flattenings of the neurilema. That the same arrangement obtains in the substance of the ventricles which prevails on the surface may be readily made out by tracing the nerves into the substance of the larger hearts, as, for example, those of the horse, ox, camel, &c. On the anterior surface of both ventricles of the human heart large numbers of nerves may be seen dipping into the muscular substance, and by exercising extreme care they can be traced for a considerable distance.

The arrangement of the nerves in the heart of the camel, alpaca, panther, seal, and all the other mammals which I have examined, is in every respect similar to that already described in the calf and in man.

§ 183. Microscopic Appearances presented by the Ganglia found on the Coronary Sinus and Cardiac Vessels.

The ganglia of the heart vary greatly in size, some being so minute that a pocket lens or microscope is required to detect them ; others being so large as to be readily recognised by the unaided eye even at a distance. In every case they are characterised by an increase of nerve-substance, the aggregate of any one ganglion being greater than the aggregate of the nerves which enter and leave it. The increase in bulk is due for the most part to the presence of an infinite number of unipolar nerve-cells mixed with a few bipolar ones.[1] The ganglia also vary in form. Thus some are stellate-shaped, others quadrangular, others oblong, others triangular, and others spindle-shaped. The form depends in a great measure on the number of nerve-filaments which conduct to and from the ganglia. Thus, if a ganglion is connected with eight nerve-filaments, it is stellate-shaped ; if with four, quadrangular or oblong ;

[1] Similar ganglia are found in the stomach, intestines, bladder, uterus, and certain of the blood-vessels ; and it is worthy of remark, that the structures here enumerated are endowed with more or less typical rhythmic movements.

if with three, triangular; and if with only two, spindle-shaped. The spindle-shaped ganglia are found where the nerves cross the smaller vessels; the others on the coronary sinus and larger vessels, and on the surface, and in the substance of the heart generally, particularly where the nerves bifurcate and break up with a view to changing their direction. The ganglia consist for the most part of irregular aggregations of nerve-cells, with nerve-filaments proceeding to and from them (Fig. 220, C). This is the character of the irregular-shaped ganglia found on the coronary sinus. In other cases, the aggregation of nerve-cells assumes an oval form, the nerves proceeding to and from the cells being arranged in two sets, as witness the spindle-shaped ganglia found on the nerves as they cross the smaller vessels (Fig. 220, B). In other cases the nerve-cells are disposed in the form of a bulb, the nerves conducting to and from the nerve-cells being arranged in a fasciculus; the ganglion with its leash of nerves resembling a hyacinth bulb with its stem (Fig. 220, A). Wherever a large terminal ganglion is found, one or more smaller ones, apparently in process of formation, may be detected. The following is the arrangement as ascertained by me in 1861: "The bundles of nerve-filaments on entering the clump (terminal ganglion) resolve themselves into their component nerve-fibres, and each fibre selects and becomes connected with a nerve-cell." [1]

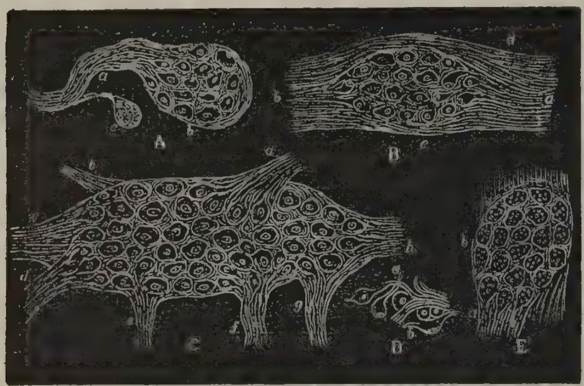


FIG. 220.—A. Large and small terminal ganglia with nerve-cells and nerve-fibres proceeding to and from them. *a*, Bundle of nerve-filaments in connection with large ganglion (*b*). A similar bundle is connected with small ganglion (*c*), (the Author, 1860).
B. Ganglionic enlargement or swelling of nerve as it crosses a vessel. *a*, *b*, Nerve-filaments proceeding to and from the ganglion and nerve-cells (*c*); *d*, nerve-substance surrounding and investing ganglion (*c*), (the Author, 1860).
C. Large ganglion crowded with nerve-cells from coronary sinus of calf. *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*, Nerve-filaments proceeding to and from the ganglion and nerve-cells. The nerve-cells contain a nucleus and one or more nucleoli. They are for the most part unipolar in character. A few bipolar nerve-cells are also found (the Author, 1860).
D. Unipolar (*a*) and bipolar (*b*) nerve-cells from cardiac ganglion, displaying nucleus and nucleolus (the Author, 1860).
E. Terminal ganglion or aggregation of cells in a nerve as it crosses a vessel. *a*, Nerve-filaments proceeding to and from the nerve-cells of the terminal ganglion (*b*), (the Author, 1860).

In order to see the nerve-cells to advantage, the best plan is to take a fresh heart and remove one of the ganglia from its surface in such a manner as not to injure or compress it in any way. This done, the ganglion is placed in an ammoniacal solution of carmine for a short time. The unequal staining produced by this pigment differentiates the nerve-cells and nerve-filaments. The ganglion is then transferred to a glass slide and a little glycerine added, with a view to examination with a low power. The ganglion thus prepared shows the dark central mass of the nerve-centre and the lighter nerve-filaments in connection therewith. A trained eye may also detect traces of the nerve-cells, which appear as dark rounded masses. To see the nerve-cells properly, the ganglion, if large, must be broken up with needles; if small, a thin covering-glass should be employed, and pressure applied with a view to flattening and even crushing it. A microscope, magnifying from 300 to 400 diameters, will reveal the nerve-cells as represented at Fig. 220, A, B, C, D, E. These figures are copied from my Inaugural Dissertation, deposited in the Library of the University of Edinburgh in 1861, and it will be observed that they remarkably accord with analogous figures representing the ganglia and nerve-cells in the heart of the frog, published by Dr. Beale in 1863.

The cells are for the most part unipolar, with a liberal sprinkling of bipolar ones (Fig. 220, D). They contain a nucleus and one or more nucleoli (A, B, C, D). In some cases and under certain conditions they present a granular appearance (E). Analogy inclines me to believe that the ganglia and nerve-cells just described are to be regarded as nerve-centres or diminutive brains. In this I agree with Winslow, Winterl, Johnstone, Unger, Lecat, and Peffingers. They assist in regulating and co-ordinating the movements of the heart, and preside over its nutrition. This view, if taken in connection with the vital properties inhering in involuntary muscles, in part accounts for the rhythmic movements of the heart when the organ is cut out of the body, when it is severed from its nervous connections, and when it is deprived of blood, unless such as is found within its walls. It is the blood within the muscular parietes of the heart which keeps it alive and enables it to move rhythmically.

§ 184. Why does the Heart act Rhythmically?

To this question no satisfactory reply can be given in the present state of science. The older observers attributed the phenomenon to various and extraordinary causes. Stahl, for example, declared the movements of the heart to be under the guidance of the *anima* or soul. Sylvius, the head of the chemical sect, traced them to an

[1] Inaugural Dissertation by the Author, "On the Ganglia and Nerves of the Heart, &c.," p. 36. University of Edinburgh Library, 1861.

effervescence caused by a mixture of the old and alkaline blood with the acid chyle and acid pancreatic juice; while Descartes referred them to a succession of explosions occurring within the heart due to a generation of steam. Willis, with a greater show of reason, attributed the movements of the heart to the cerebellum and the eighth pair of nerves. To these Boerhaave added two additional causes, namely, the action of the blood of the arteries on its fibres, and of the venous blood on the surface of its cavities. The hypothesis of Willis explained how the heart is subject to the storm of the passions, but it did not explain how the heart pulsates in the *anencephalous* fœtus (fœtus devoid of brain and spinal cord), or in animals whose brain and spinal cord were crushed or removed. Still less did it explain how the heart moved with a regular rhythm, when cut out of the body, deprived of its blood, and placed in an exhausted receiver with a view to excluding the air which was supposed to act as an irritant. This difficulty induced Haller to deny that the heart owed its movements to its nerves, and led him ultimately to declare that the movements of the heart are due to irritability inhering in the muscular fibres (*vis insita*) as apart from its nerves. Haller's theory failed to account for the presence of nerves on the surface and in the substance of the heart, and for the connection which is known to exist between that organ and the head. Some of his followers, Soemmering and Behrends for instance, endeavoured to evade this difficulty by supposing that the cardiac nerves were distributed only to the vessels of the heart; a view which, in the present state of the subject, is untenable. Stannius, in recent times, has made experiments to show that the rhythm of the heart is referable to its ganglia, which he regards as automatic nerve-centres; and Sir James Paget argued with much ability to the effect that it is due to rhythmic nutrition. There are no sufficient grounds for believing that the nerves actually produce the movements of the heart. These in all probability originate in the sarcous elements composing the muscular fibres of the heart, as is partially demonstrated by the following experiment: When the nerves proceeding to a muscle are poisoned by certain substances, such as woorara, so that stimulation of the nerves fails to produce shortening or contraction of the muscle, the muscle may nevertheless be made to shorten by applying the stimulus to its muscular fibres directly. Furthermore, Bowman asserts from observation, that a muscular fibre destitute of nerves may be made to contract. The heart acts rhythmically for protracted periods after it is cut out of the body and its nerves divided [1]—a circumstance which compels us to conclude either that the rhythmic movements inhere in the muscular substance or that they are referable to the ganglia which are found in great numbers on the surface and in the substance of the heart generally. But, as has been stated, the nerves may be poisoned, and the heart may still contract under direct stimulation. The will exercises no influence upon the movements of the heart under ordinary circumstances, and the brain and spinal cord may be crushed without interfering with them even in a remote degree. In the *anencephalous* fœtus, where the brain and spinal cord are absent, the heart acts rhythmically and regularly. On the other hand, it is well known that certain mental states (joy, grief, &c.) affect the heart, and that division of the pneumogastric nerves is followed by a quickening of the heart's action, while irritation of the cut ends of these nerves is accompanied by slowing of the heart's action. Division of the nerves tends to prove the regulating influence of the nervous system; the cause of the rhythm of the heart remaining still unexplained. Sir James Paget, whose philosophic utterances have necessarily great weight, was disposed, as already stated, to attribute the rhythm of the heart to rhythmic nutrition. This, however, cannot be accepted as the final explanation; for one naturally inquires, Why should the nutrition of the heart be rhythmic, seeing it is only a muscle, and there are innumerable other muscles equally well nourished whose movements are not rhythmic in the ordinary sense?

There is a further difficulty as to whether nutrition is to be accredited with the movements, for cilia vibrate rhythmically when removed from the body, and even when on the verge of putrefaction. Granting, however, that the rhythmic nutrition of the heart produces its rhythmic movements, the question still remains (and it is equally hard of solution), What causes the rhythmic nutrition? The rhythmic nutrition hypothesis only removes the difficulty one step further back; it cannot be accepted as a final explanation. All nutrition is not rhythmic, and when it is, there must be laws to regulate it. Those laws are as yet undiscovered, and are probably only to be recognised by their effects. For reasons to be stated presently I am disposed to believe that the rhythmic movements of the adult heart are inherent and fundamental, but are due partly to a healthy nutrition, and partly to the influence exerted on the cardiac movements by the ganglia and nerves situated on its surface and in its substance. There can be no doubt that the nervous system presides over the nutrition of the circulatory apparatus as a whole, and it is equally evident that the movements of the heart and blood-vessels, and the degree of vascular tension or pressure, are modified by the condition of certain nerves and nerve-centres. With a view to simplifying our comprehension of this very involved but highly interesting problem, I propose to arrange existing materials under two heads:—

I. Proofs that the heart can move independently of the nerves.

II. Proofs that the movements of the heart are regulated and co-ordinated by the nerves.

[1] The heart of the frog, if supplied with fresh *serum*, will pulsate for several days after removal.

§ 185. Proofs that the Heart may act independently of the Nerves.

Analogy favours this view.

(*a*) Certain plants when vigorous and exposed to a bright light, such as the *Hedysarum* (*Desmodium*) *gyrans*, exhibit rhythmic movements.

(*b*) Professor Busk showed that at a certain period of the development of the *Volvox globator* (a very simple vegetable organism), there appear in each zoospore, or in the bands of protoplasm with which the zoospores are connected, vacuoles, spaces or cavities, of about $\frac{1}{5000}$ of an inch in diameter, which contract with regular rhythm at intervals of from 38 to 41 seconds, quickly contracting and then more slowly dilating again, as in the heart.

(*c*) Similar phenomena were observed by Cohn to occur in *Gonium pectorale* and *Chlamydomonas*, the vacuoles or water vesicles contracting regularly at intervals of from 40 to 45 seconds. Here, of course, neither nerve nor muscle, nor blood, nor any kind of stimulus, or anything in the shape of irritation, is present. Sir James Paget attributes the rhythmic movements in plants to rhythmic nutrition. This, however, as already stated, can only be accepted as a partial explanation. All nutrition is not rhythmic. Only certain plants exhibit rhythmic movements, but all plants are equally well nourished.

(*d*) Rhythmic movements occur in cilia, these, so far as known at present, not being supplied with nerves. That ciliary movements, at least, are not due to rhythmic nutrition appears from this, that cilia vibrate rhythmically when removed from the body, and even when on the verge of putrefaction.

(*e*) The amœba, which consists of an undifferentiated mass equally devoid of nerve and muscle, can change shape in every direction, and can open and close any part of its body to produce a temporary stomach.

(*f*) The heart pulsates while yet a mass of nucleated cells—that is, before it is furnished with either muscular fibres, nerves, or blood.

(*g*) Bowman showed that a muscular fibrilla, on or in which no nerve can be detected, may be made to contract artificially.

(*h*) The brain and spinal cord may be gradually crushed without in the slightest disturbing the movements of the heart (Marshall Hall).

(*i*) The branches of the pneumogastric nerves which supply filaments to the heart have little or no sensibility, and the filaments supplied to the organ by the sympathetic trunks only act upon it after being stimulated a short time previously.

(*j*) The great sympathetic nerves which furnish the principal nervous supply to the heart in the mammal are particularly sluggish in their action, and when stimulated affect the movements of the heart only after a considerable interval; the effect produced not ceasing when the stimulation is discontinued.

(*k*) When woorara poison has been administered to an animal, it completely paralyses the motor nerves, leaving the sensory nerves and muscular irritability intact. Under these circumstances the muscular fibres may be made to contract by the direct application of a stimulus, showing that movement inheres in the sarcous elements of the muscular fibres of the heart. This power of moving on the application of a stimulus which inheres in muscle was designated by Haller the *vis insita*.

(*l*) When an animal is poisoned by woorara, and the rhythm of the heart maintained by artificial respiration, the galvanisation of both pneumogastric nerves does not affect its movements. If the penumogastrics be powerfully galvanised the heart is stopped for a short period, but resumes its functions as soon as the motor filaments are temporarily exhausted and deprived of what is termed their inhibitory or slowing power (Bernard).

(*m*) In birds, according to Bernard, galvanisation of the pneumogastric nerves does not affect the heart.

(*n*) The heart may be cut out of the body and deprived of blood, and still beat regularly. This experiment shows either that the movements of the heart are independent of the nerves as a whole, or are referable to the nerves and ganglia situated on its surface and in its substance; but, as has been already explained, the nerves of the heart may be paralysed by woorara poison in such a manner that they do not respond to stimuli; the muscular fibres, on the other hand, responding to the stimuli as if no poison had been administered. The latter fact inclines to the belief that the motor power of the heart resides in its muscular fibres.

(*o*) Many physiologists maintain that the rhythmic movements of the heart continue not only in the heart as a whole when its cerebro-spinal and sympathetic connections are severed, and when it is removed from the body and deprived of blood, but also in fragments of the muscular substance in which no ganglia or nerve-centres can be discovered. Those who oppose this view aver that nerve-cells can, as a rule, be detected in the pulsating shreds, whereas they are absent in the non-pulsating shreds. This, however, does not always hold true.

§ 186. Proofs that the Movements of the Heart are Regulated and Co-ordinated by the Nerves.

That the movements of the heart are regulated and co-ordinated by the nerves, is proved indirectly by the following considerations :—

(*a*) Their presence on the organ and the fact that the nerves exercise a marked influence on the movements of voluntary muscles ; the voluntary muscles, as has been shown, being a differentiation and development of the involuntary.

(*b*) Mental excitement arising from sudden joy, &c., quickens the movements of the heart.

(*c*) The heart may be stopped indirectly by a voluntary effort. This is effected, first, by distending the lungs, stopping the mouth and nose, and making a strong *expiratory* effort ; and, second, by partially emptying the lungs, stopping the mouth and nose, and making a strong *inspiratory* effort. These are dangerous experiments.

(*d*) The direct action of the pneumogastric nerves upon the heart is through their motor filaments, as shown by division of the nerves in the neck. Galvanisation of their central ends does not affect the heart, while stimulation of their peripheral ends stops it. Some experimenters, however, aver that if the nerves be divided and their peripheral ends feebly stimulated by galvanism, the action of the heart is *quickened*. These contradictory statements show that the division and irritation of nerves may yield fallacious results.

(*e*) The motor filaments of the pneumogastric nerves which act directly on the heart are derived from the communicating branch of the spinal accessory (Waller).

(*f*) When one of the pneumogastric nerves is divided in the neck of the dog, the number of pulsations of the heart is slightly increased, and the cardiac pressure, as indicated by the cardiometer fixed in the carotid artery, slightly diminished. When both pneumogastrics are divided, the beats of the heart are doubled in frequency, but are weak and tremulous. A similar result is produced if the afferent nerves of the sympathetic, which are united to the pneumogastrics, are divided. The acceleration in the latter case is produced by a so-called reflex act.

(*g*) When the pneumogastric nerves in the neck are galvanised the action of the heart is *slowed*, and if the galvanism be sufficiently powerful it is *arrested* (the brothers Weber). The action of the pneumogastrics is therefore supposed to be inhibitory.

(*h*) The heart may be stopped for a few moments by pressure on the right pneumogastric at a certain point in the neck (Czermak).

(*i*) If the action of the heart be arrested by galvanisation of the medulla oblongata, the action is resumed if both pneumogastrics be divided (Longet).

(*j*) If the pneumogastric nerves be divided in the neck, galvanism of their central ends modifies the movements of the heart, by modifying the respirations, the latter being diminished in frequency (Traube and Bernard).

(*k*) If the central extremities of the divided depressor nerves be galvanised, the heart is *slowed*, and the arterial pressure in the arteries *diminished* by a so-called reflex action.[1] The diminution of arterial pressure is not due to the slowing of the heart, for it occurs even when both pneumogastrics are divided in the neck and the action of the heart quickened (Cyon and Ludwig). These experiments are calculated to show that the depressor nerves exert a twofold influence ; namely, on the heart and on the blood-vessels.

(*l*) If the spinal cord be divided immediately below the medulla oblongata, and the cord stimulated by electricity, the arterial pressure is increased and the movements of the heart quickened (Ludwig and Thiry). The nerves by the instrumentality of which those changes are produced pass through the lower cervical ganglion, and are known as the *accelerator nerves*. They are regarded as the antagonists of the pneumogastric nerves, whose function, as stated, is supposed to be *inhibitory*.

(*m*) The filaments of the sympathetic nerves everywhere invest the heart and blood-vessels. These they supply with innumerable nerve-plexuses and ganglia, the nerves to the smaller vessels being in some cases excessively minute.

(*n*) Division of the sympathetic produces *vascular congestion and widening of the vessels* supplied by the portion of the sympathetic divided. The congestion is removed by irritating by electricity the portion of the nerve supplied to the tissues (Bernard).

(*o*) Excitation of the spinal cord of the frog by electricity causes *contraction or narrowing of the arteries* of the web of the frog's foot, and if the excitation is kept up, the circulation in the arteries is stopped.

(*p*) Direct excitation of a vaso-motor nerve causes *contraction of the arteries* to which it sends nerve-filaments. Division of a vaso-motor nerve, on the other hand, produces *dilatation*.

[1] The depressor nerve in the rabbit arises in the neck by two roots, one connected with the trunk of the pneumogastric, the other with the superior laryngeal branch. It passes down the neck, and when it reaches the chest receives filaments from the sympathetic. The nerve thus augmented passes by numerous short branches to the heart between the origins of the great vessels (pulmonary artery and aorta). Cyon finds the homologue of the depressor nerves of the rabbit in the horse. (*Brit. and For. Med.-Chir. Rev*, Lond. 1871, No. xcvi. p. 540.)

(*q*) Division of the sympathetic in the neck of the rabbit causes dilatation of the central artery of the ear; but if the peripheral end of the nerve be excited, the artery contracts (Brown-Sequard).

(*r*) If one of the splanchnic nerves be divided in the rabbit, *the arterial pressure is reduced;* but if the divided nerve be stimulated by electricity, *it is increased.*

(*s*) If a portion of the base of a frog's heart be removed with a sharp knife or scissors, it acts rhythmically; whereas a portion removed from the apex does not, as a rule, act rhythmically. This does not always hold true, but when it does, it is supposed to be due to an increase in the ganglia and nerves at the base of the heart as compared with the apex.

(*t*) If a ligature be adjusted so as to enclose or map off the sinus venosus of the frog's heart, it is found that when the ligature is tightened the sinus continues to pulsate, whereas the ventricle after a few beats is arrested in diastole. After a short interval the ventricle also begins to pulsate, but the pulsations of the sinus venosus and ventricle are no longer synchronous (Stannius). This experiment is supposed to prove that the sinus venosus contains an automatic nerve-centre, that is, a ganglion in which nerve energy is accumulated and discharged at stated intervals or rhythmically. As, however, the automatic motor centre has not been demonstrated to exist anatomically, the statement must be received with caution. Admitting, however, that the automatic motor centre really exists, the rhythm of the heart is still unexplained. The mystery of the movement confronts us as before. The question, then, comes to be, What causes the automatic motor centre to act rhythmically? The answer to this question will probably bring us face to face with the hidden springs of life itself; and the why and the wherefore of existence, there is reason to believe, will for ever remain a sealed book.

§ 187. The Theory of Irritability as bearing on the Action of the Heart, considered.

The voluntary muscles, according to Haller, are alone under the influence of the nerves; the hollow muscles, such as the heart, stomach, bladder, and uterus, not being stimulated by their nerves but by their contents. In Haller's opinion, the blood is the stimulus to the heart. Dr. John Reid also adopted this view. He says, "The ordinary and natural stimulus of the heart is the blood which is constantly flowing into its cavities. The greater irritability of the inner surface over the outer is evidently connected with the manner in which the stimulus is habitually applied. When the blood is forced on more rapidly towards the heart, as in exercise, its contraction becomes proportionally more frequent; and when the current moves on more slowly, as in a state of rest, its frequency becomes proportionally diminished. If the contractions of the heart were not dependent upon the blood, and their number regulated by the quantity flowing into its cavities, very serious and inevitably fatal disturbances in the circulation would soon take place."[1] If, however, the impinging of the blood against the inside of the heart is the cause of the heart's movements, it is natural to suppose the heart would close the instant the blood enters its cavities, without waiting until those cavities are full. If exception be taken to this statement, and it is asserted that the blood only becomes a stimulus when a certain quantity has been collected, then we are equally entitled to assume that the heart has become accustomed to the stimulus up to a certain point. But if so, seeing the heart is always receiving blood, why does it not become altogether accustomed to the presence of blood, and the blood cease to act as a stimulus? I will go further, and ask, how can the blood possibly act as a stimulus to the dilating ventricles? Again, how comes it that the blood acts as a rhythmical stimulus? When the ventricles have closed, every drop of blood is literally wrung out of them. The ventricles, in fact, at the end of the systole, form a solid mass. The auricles have no power to force blood into a solid muscular mass; and, if the blood be not present, it cannot act as a stimulus. The heart, moreover, closes and opens when removed from the body and placed in an exhausted receiver, and when neither blood nor air is present. I have on many occasions made transverse sections of human and other hearts when in the contracted state, and have satisfied myself that the ventricles can completely obliterate their cavities.

The ventricles of the heart occlude their cavities in the following manner:—Towards the ends of the systole, the walls of the ventricle thicken to a marked extent; the ventricles become shorter; the musculi papillares shorten and twist and plait into each other, and the auriculo-ventricular valves are dragged down into the ventricular cavities to form two dependent twisted cones. The thickening of the ventricular walls from without inwards, aided by the shortening of the more oblique spiral fibres, tends to diminish the ventricular cavities from side to side; while the shortening of the more longitudinal spiral fibres and spiral musculi papillares, aided by the descent of the auriculo-ventricular valves, diminishes the cavities from above downwards. The apices of the ventricles are

[1] "Physiological, Anatomical, and Pathological Researches," by John Reid, M.D., F.R.C.P. Edin., Chandos Professor of Anatomy and Medicine in the University of St. Andrews, &c., 1848.

closed by the shortening and thickening of the spiral fibres in those regions; the spiral fibres, particularly of the left apex, forming a whorl or vortex of great beauty. The spiral fibres, by their shortening and thickening, press the walls of the apices forcibly together, in a direction from without inwards and from below upwards, and so convert them into a solid muscular mass. This is necessary, because the apices are the weakest portions of the ventricular walls—the left apex of even the horse's heart being only $\frac{1}{8}$ of an inch or thereby in thickness; that of the human heart being little over $\frac{1}{16}$ of an inch. The tenuity of the ventricular walls at the apices enables the several orders of spiral fibres to coil and uncoil with great facility during the systole and diastole, when the fibres of the heart screw home and then unscrew.

That no blood is contained in the ventricular cavities at the termination of the systole, is proved by the fact that in animals bled to death the ventricular cavities are, for the most part, completely obliterated. This arises from the surfaces of the ventricular walls, which are directed towards the axes of the cavities, being closely and accurately applied to each other throughout.

In the frog and other animals with semi-transparent hearts, the ventricle is blanched at the end of the systole —an appearance due, not, as was thought, to the absence of blood in its walls, but in its interior. The impinging of the blood against the endocardium cannot, therefore, be regarded as the prime mover of the heart. As well might we say that the presence of the pericardial fluid and the impinging of the exocardium or outer surface of the heart against the pericardium was the source of its activity. This would be an equally if not a more satisfactory explanation, the more especially as there is, as has been shown, a superabundant supply of nerves and ganglia on the external surface of the heart.

That the doctrine of irritability is hypothetical or has elements of fallacy in it is, I think, proved by the movements in plants, cilia, the worm, the tentacles of the snail, sea anemone, and allied structures, already described. It seems also proved by the movements of the hollow viscera as a class. If the contents of the hollow viscera acted as stimuli to them, these organs could not consistently be employed as *receptacles* either for living or dead matter. If the blood formed the stimulus for the heart, the food for the stomach, the urine for the bladder, the fæces for the rectum, and the fœtus for the uterus, these organs would eject their contents, not at stated intervals, but whenever the stimulus was applied to them. It would be impossible, I apprehend, to apply the stimulus of electricity to any one of them, without producing violent contraction or closure of their muscular walls; nor would this state of matters be improved by keeping up the electricity with a view to familiarising them with it, as this would result in paralysis. The hollow viscera are living muscles; they open up, to receive the substances prepared for them, and when they have received the full measure thereof, they close and expel them according to fixed laws, and independently of irritation. If the closing of the hollow viscera was due simply to irritation, our bodies would not be the really comfortable habitations they are in a state of health. I am disposed to believe that a living organism has the power in all its parts of avoiding or rejecting, and selecting and appropriating, whatever it chooses. It is this power which makes it superior to the outer world in which it lives, moves, and has its being. It is more rational to suppose that a living creature, or a part thereof, controls or avoids the inanimate matter by which it is surrounded, than that the inanimate matter inaugurates and controls its movements. For my own part, I cannot for a moment imagine that the presence of the urine and the fæces in the bladder and rectum act as irritating stimuli. I can still less believe that the blood and fœtus act as such to the heart and uterus. This view will no doubt be met by the old hypothesis, that we may have an irritable stomach, bladder, or rectum, and that under these circumstances the viscera close as soon as anything is placed within them. If this theory proves anything, it proves that, in a normal or healthy condition, the contents of the hollow viscera do not act as irritants. I am aware that those who hold the doctrine of irritability in its entirety, assert that, when a call is made to pass fæces or urine, and the call is not attended to, the uneasy feeling passes away, because the viscus becomes accustomed to the irritant which is stimulating it. Would, let me ask, the viscus become accustomed to the presence of a coil of wire in its interior conveying electricity? The fact that the uneasy feelings do pass away when the call is not attended to, shows conclusively that the contained matter is not an irritant in the ordinary acceptation of the term. It is very difficult, I believe impossible, to reconcile the theory of irritability with vital manifestations in a healthy organism. The effects produced by artificial stimuli are, I strongly suspect, calculated to mislead. Even the amœba, which is a mere protoplasmic jelly-like mass, has the power of taking in, containing, and ejecting at will, the dead or living matter on which it depends for support; and it will take no great stretch of the imagination to believe that the hollow viscera are provided with a like power, the more especially as they are abundantly supplied with blood, and provided with innumerable nerve-plexuses and ganglia. In swallowing, the œsophagus seizes and transmits the food intended for the stomach, the muscular walls of this tube closing or contracting behind the bolus, and expanding or dilating in front of it—a fact inconsistent with the doctrine of irritability; for in that case the œsophagus would close before the bolus, and not behind it. The stomach, when it has received the food which constitutes a meal,

immediately sets to work upon it, and causes it to travel in certain given directions in its interior, until, in conjunction with the gastric and other secretions, it reduces it to a pulp (chyme). This done, it opens its pyloric valve, and causes the more fluid portions of the mass to pass into the duodenum. The pyloric valve is then closed, and the contents of the stomach rolled about as before. The pyloric valve is a second time opened, and the more pultaceous portions of the digesting mass ejected. The pyloric valve is a second time closed, and the contents of the stomach again rolled about and manipulated as by an intelligent agent. The pyloric valve is opened a third time, and the entire contents of the stomach ejected.[1] Now, it will be observed that it cannot be the supposed irritation produced by the food which causes the movements of the stomach; for in that case, the food would be expelled immediately it came in contact with the lining membrane of the stomach, which it is not. If, moreover, the food be regarded as the irritant which causes the body of the stomach to close or contract, it cannot consistently be regarded as the irritant which causes the pyloric valve or sphincter of the stomach to open, as these are opposite acts, and the sphincter lies beyond the source of the irritation. What is said of the stomach applies equally to the heart, the bladder, the rectum, and the uterus. All these have a common structure and a common nervous supply, and the movements are, strictly speaking, rhythmic in character.

The bladder in a healthy subject acts from four to six times in the twenty-four hours, that is, it receives and retains a fluid for six hours at a time, without causing the slightest inconvenience. During that period the urine certainly does not act as an irritant in the common acceptation of the term, yet this same fluid at the end of the sixth hour is said to occasion its own expulsion. It could only do so by being suddenly transformed into a highly irritating fluid, which its presence in the bladder for six hours proves it not to be. But granting that the supposed irritating nature of the fluid at the sixth hour caused the body of the bladder to contract, it could not possibly cause the sphincter of the bladder to open, as this is an opposite act, and the sphincter is placed beyond the reach of the irritating medium. If I am here met by the argument, that it is the irritation produced by the increased pressure of the urine at the sixth hour, I reply that the bladder may be completely emptied, and, in a few minutes, a teaspoonful or so of urine may be extruded by a voluntary effort. This completely disposes of the increased urine pressure theory. I will add that the increased fluid pressure theory cannot apply in the case of the stomach; that viscus having the power to discharge the chyme to its last drop into the duodenum. The stomach and bladder, as has been pointed out, have a common structure and a common nervous supply. Similar remarks may be made of the rectum and its sphincters. The rectum in a condition of health receives fæces for twenty-four hours, or thereby, at the expiry of which period it closes by a rhythmic movement and expels its contents. The closing of the body of the rectum is accompanied by the opening of its sphincters, but the former act does not produce the latter, both being equally vital in their nature. The uterus in the human subject retains its contents for nine months. During this long period (and the term is greatly exceeded in the case of the elephant), the fœtus, notwithstanding its vigorous movements and ever-varying position, occasions little or no inconvenience to the mother. It is assuredly not to be regarded as an irritant. After a few incipient contractions of the uterus (the false pains of obstetricians), occurring at intervals during the period of gestation, and a few vigorous contractions (the true pains of obstetricians) at the full term, the fœtus is thrown off or expelled. While the body of the uterus is contracting or closing, the os or sphincter of the uterus is expanding or opening. These acts are independent and separate, and constitute the rhythm of the organ.

But to return to the heart.

The heart beats, because its elementary particles—that is, its ultimate or sarcous elements—live. If a potent poison be introduced into the substance of the heart, the particles die, and the heart ceases to act both within and without the body. If, moreover, the nerve-plexuses of the heart be suddenly destroyed, and the nutrition of the heart impaired, the action of the organ becomes irregular, or altogether ceases. The blood within the substance of the heart, and not within its cavities, is the cause of its movements, and these movements are not due to irritation but to a healthy nutrition and assimilation, which go on so long as the body lives and the heart beats. That the movements of the heart are not due to the blood which it contains in its several cavities acting as a stimulus is, I think, apparent from Dr. John Reid's own writings. In his admirable paper on the "Heart," he states that in extensive injuries to the central organs of the nervous system, such as concussion of the brain, severe mechanical injuries, the shock after operations, extensive burns, peritonitis, &c., the quantity of the blood entering the heart is reduced, the action of the heart quickened, and its contractility lessened. The frequency of the heart's action in man varies at different periods of life. Thus, in the human fœtus, the heart beats 140 times per minute; at birth, 130; second year after birth, 100; third year, 90; fourteenth year, 80; middle age, 70; old age, 60, or even less. The variations in the frequency of the beat of the heart in the lower animals are still more remarkable. If, however, the blood contained within the cavities of the heart stimulates the organ to contract, how, it may be asked, are

[1] In the case of Alexis St. Martin, who had the anterior portion of his stomach removed by a gunshot wound, these movements could be seen.

the contractions more frequent when the supply of blood is reduced, and the contractile power of the organ diminished? The heart, as I have already pointed out, does not, in a state of health, contract the instant the blood touches its interior; on the contrary, its several parts do not begin contracting until they have received all the blood they are capable of containing. If, however, the heart, under certain circumstances, contracts more frequently when it contains a small quantity of blood, and its supposed irritability is diminished, than when there is a full supply of blood and its supposed irritability is greatest, then we are, I think, entitled to conclude that the blood contained within the cavities is not the cause of the movements of the heart. Furthermore, it is known that arterial tension or fulness retards rather than increases the heart's action; the pulsations being fewest when the blood is, as it were, dammed up in the heart. If, for example, the aorta is compressed, the pulse rate is at once diminished. The injuries to which Reid alludes most probably change the character of the heart's action by paralysing or otherwise impairing the function of the nerves which regulate its nutrition. The rapid feeble pulse in the cases referred to is rather to be attributed to the fact that the vitality of the heart is temporarily lowered, and that it only admits a minimum quantity of blood as it has not the power to expel the maximum quantity. In the same way, in certain chest complaints, the respiratory efforts are increased in frequency—the inspiratory and expiratory acts being decreased in duration. Dr. Kay furnishes a direct proof that the presence of blood within the cavities of the heart is not the cause of the movements of the heart. In his experiments on asphyxia, he describes how the left side of the heart dies. He says, "A smaller quantity of blood is received into its cavities and expelled vigorously into the arteries. The ventricle, meanwhile, diminishes in size as the quantity of blood supplied becomes less, until at length, although spontaneous contractions still occur in its fibres, no blood issues from the divided artery, and the ventricle, by contraction, has obliterated its cavity." As a further proof that the heart does not depend for its movements on the blood it contains, the following experiment may be cited:—If a frog be slightly curarized and its spinal cord destroyed, it is found on exposing the heart that the sinus venosus, vena cava inferior, the auricles and ventricle, are quite destitute of blood, and yet the organ beats normally and with the utmost regularity. The heart also beats normally when cut out of the body, *deprived of blood*, and placed under a bell-jar. Furthermore, the interior of the heart, as M. Chauveau has shown, is almost devoid of sensibility. He proved this by introducing small caoutchouc bags (cardiac sounds) into the cavities of the ventricles of the horse, without causing the animal either pain or inconvenience.

Brief Summary of the Circulation.

In taking a backward survey of the great subject of the circulation in plants, in the lower animals, and in man, one is struck and, in a sense, bewildered by the extraordinary numbers of structures and forces employed. There is scarcely any mechanical contrivance which is not brought into requisition. The simplest and most complex plant and animal structures are engaged in inaugurating and carrying on the circulation.

To trace the flow of the nutritious juices through plants and animals is a well-nigh hopeless task, and the blending and utilisation of the vital and physical forces furnish endless examples of forethought, design, and continued supervision.

The vital and physical forces are not confined to the adult plants and animals. On the contrary, they are at work during conception and embryonic life as well as during adult life. The nutritious juices of plants and animals must circulate and move freely about in organised bodies, whatever their shape, properties, and ultimate composition. It is not automata with which we have to deal in plants and animals, but with living entities capable of circulating and guiding their nutritious juices under varying conditions with or without tubes, vessels, and valves.

The organic forces are in every instance superior to the inorganic ones, which they employ or not according to circumstances and to given ends.

The movements and workings of plants and animals are not only spontaneous, they are also, after a fashion, more or less voluntary. Nothing short of a First Cause, design, and continued supervision can afford a satisfactory explanation of all the phenomena.

In the circulation we have to consider a mass of structural and physiological details—some simple and some very involved. It is not a question of a purely mechanical apparatus as against a purely vital one, but of a vito-mechanical apparatus as against both; an instance where the living meets the dead and utilises whatever there is of value in it. To take an example, a dead animal applied to the roots of a living plant is one of the best fertilisers.

In growing upwards the plant acts in opposition to the great law of gravitation. This crowning force, which may be said to rule all the other physical forces, is habitually set aside by the forces of the growing plant. The other physical forces share a like fate when they obstruct development, especially in an upward direction. Living animals obtain their forces indirectly through the plants. If plants are well fed, their circulation is vigorous. The same is true of animals. The first sign of a seriously impaired state of health is a disturbed, feeble circulation.

What distinguishes the circulation is its extent and labyrinthine character. It begins as a simple process of absorption and assimilation in which no distinct mechanism can be made out; it ends in an exceedingly complex system with a highly differentiated apparatus, in which may occur a heart, vascular vessels, valves, &c.

Each part of the circulation in the higher animals is very intricate and also very powerful. The heart is the strongest and most complex muscle known, and the valves display an amount of mechanical contrivance which can nowhere be matched in the animal economy. The heart, vessels, and valves form an elaborate force-pump, which has its parts so arranged that it is incessantly taking in and giving out fluid, so that it loses no time in forcing forward the nutrient fluids of the body through considerable distances, always in one direction, by means of the larger vessels, and through short distances by the aid of the capillary vessels.

It would be easy to extend this summary very considerably, but in order to do so satisfactorily large portions of the text would require to be reproduced. This, for several reasons, is undesirable, and my original purpose has been sufficiently secured by what is stated above in an admittedly very imperfect and fragmentary form.

THE MOVEMENTS AND FUNCTIONS OF SENSITIVE, INSECTIVOROUS, CLIMBING, AND OTHER PLANTS.

It has been shown that certain plants move in definite directions and to given ends as apart from irritability and every form of external stimulation.

It has now to be shown that there are plants which not only move to given ends but which are sentient, feel, and move, in a sense, intelligently—if indeed the term intelligence can be applied to any living thing not possessed of a well-defined nervous system and brain.

The sensitive, insectivorous, and climbing plants supply examples.

Under sensitive plants may be classed *Æschynomene sensitiva, Averrhoa Carambola, Desmanthus lacustris, Neptunia plena, Smithia sensitiva*, &c.

Under insectivorous plants fall certain pitcher plants, Venus's fly-trap (*Dionæa muscipula*), the sundew (*Drosera rotundifolia*), the butterwort (*Pinguicula vulgaris*), *Bartsia alpina*, &c.

Under climbing plants are to be grouped the hop, honeysuckle, sweet pea, convolvulus, passion-flower, vine, gourd, cucumber, vegetable-marrow, &c.

Before dealing with the sensitive, insectivorous, and climbing plants in the above order it may be useful to give a brief epitome of the movements of plants in general. The following pertinent remarks on this most interesting subject are furnished by Professor J. Hutton Balfour, who adopts Schleiden's classification of plant movements :—

" Certain leaves display evident movements under the influence of light, heat, and a stimulus either of a mechanical or chemical nature. The effects of light and darkness are frequently very marked in causing the elevation and depression of leaf-stalks, and the expansion and folding of leaves. The changes which take place in leaves during darkness were included by Linnæus under what he called the *sleep of plants*. During darkness leaves often hang down, and, in the case of compound leaves, there is also a folding of the leaflets, either in an upward direction, as in the sensitive mimosas, or downwards, as in *Tephrosia caribœa*. Hoffmann thinks that the sleeping and awakening of leaves are due to temperature, and that light only influences the phenomenon in so far as it contains calorific rays. Plants expand their leaves after the receipt of a certain sum of degrees of temperature.[1]

" Very obvious movements occur in the leaves of many species belonging to the natural orders Leguminosæ, Oxalidaceæ, and Droseraceæ. Among leguminous plants may be noticed species of Mimosa, Robinia, Æschynomene, Smithia, Desmanthus, and Neptunia ; in the family of Oxalidaceæ, many species of oxalis exhibit a certain degree of irritability,[2] but it is chiefly observed in the pinnate-leaved *Biophytum sensitivum ;* while among Droseraceæ the leaves of *Dionæa muscipula* have a remarkable irritability ; and those of the species of Drosera also exhibit traces of it. In some plants the movements are most marked in the young state.

" The movements exhibited by the leaves of plants may be divided in the following manner : [3]—

" 1. *Movements which depend upon the periodical returns of day and night.*—Under this head are included the phenomena of the sleeping and waking of plants, which are influenced solely by light and darkness. In general the parts during the night resume, as far as possible, the position which they occupied in the bud, and this the more accurately, the younger and more tender the leaf.

[1] Hoffmann, "Untersuchungen ueber den Pflanzenschlaf;" "Sur le Sommeil des Plantes." (*Annales des Sc. Nat.*, 3rd ser. Bot. xiv. 310 ; also *Botanical Gazette*, iii. 62.)

[2] For the term irritability employed here and elsewhere I am disposed to substitute that of sensitiveness. A living thing may be sensitive which is not in the least degree irritable (*vide infra*).

[3] Schleiden's "Principles of Botany," translated by Lankester, p. 551.

"2. *Movements which, besides being influenced by light and darkness, are also occasioned by any external or chemical agency, as evidenced by the following sensitive plants :—*

"Æschynomene indica.
,, pumila.
,, sensitiva.
Averrhoa Bilimbi.
,, Carambola.
Biophytum (Oxalis) sensitivum.
Desmanthus lacustris.
,, stolonifer.
,, triqueter.
Dionæa muscipula.
Drosera rotundifolia, and other species.
Mimosa asperata.
,, casta.
,, dormiens.
,, humilis.
,, pellita.
,, pernambucana.
,, pigra.
,, pudica.
,, quadrivalvis.
Mimosa sensitiva.
,, viva.
Neptunia plena.
Oxalis Acetosella.
,, carnosa.
,, corniculata.
,, deppei.
,, purpurea.
,, stricta.
Smithia sensitiva.

"3. *Movements independent, to a certain extent, of external influences, as in some of the leaflets of—*

"Hedysarum cuspidatum.
,, gyrans.
Hedysarum gyroides.
,, lævigatum.
Hedysarum vespertilionis."[1]

With regard to the terms irritability and stimuli employed by Professor Balfour, and botanists generally, when speaking of the activities and movements of plants, I have to observe that they often lead to confusion, and are not, strictly speaking, applicable to either plants or animals.

Stimuli, as a rule, are not necessary to the due performance of the functions of plants and animals, and irritability, in reality, means sensitiveness.

Living plants and animals are, or may be, sensitive without being irritable. They may even respond to external influences without a trace of irritability. Irritability bespeaks an abnormal condition and suggests discomfort. Healthy plants and animals with natural surroundings act independently and as apart from either irritability or stimulation. The presence of suitable pabulum in the case of plants and animals does not produce irritation or stimulation in the ordinary sense. On the contrary, the ingestion of desirable and appropriate food begets a feeling of comfort and satisfaction. To take an example, food placed in the mouth is accompanied by a flow of saliva. Saliva will, however, flow on smelling food, or at the thought of a savoury meal. Here the function is evoked in the absence of the substance which is supposed to excite it. The food is not the sole cause of the flow, and it is not a mere question of stimulation and irritability. Similarly, the gastric juice is induced to flow not because of the supposed irritability of the mucous lining of the stomach and the contact or stimulation of a foreign substance. In the case of Alexis St. Martin, the interior of whose stomach, on account of a gunshot wound, could be examined, a catheter placed in the stomach produced no gastric juice, whereas a piece of under-cooked, juicy beefsteak occasioned a copious flow. The stomach distinguished between what was food and what was not food, and so displayed a low form of cognition.

The insectivorous plants do the same thing. In the sundew, for example, if edible particles be allowed to drop on its leaves covered with highly-sensitive hairs, the hairs or tentacles bend, and convey by a rolling movement the particles to the middle of the leaf, where an acid secretion containing a ferment akin to gastric juice is produced and the particles digested and assimilated. If the particles are non-edible, no digesting secretion is poured out, and the particles themselves are gradually extruded and got rid of. A distinction must be drawn as between sensitiveness and irritability on the one hand, and between extraneous stimulation and the independent movements of plants and animals on the other. A low form of cognition and selective power must also be conceded. Plants and animals act, or cease to act, at discretion. They are not mere automata goaded into activity by supposed irritability and the extraneous stimulation believed by the majority of authors to be produced by foreign matters.

§ 188. Sensitive Plants.

The sensitive plants are especially deserving of attention. In the whole range of plant life there is nothing more remarkable or striking than the movements of the so-called sensitive plants. Some of them respond to the touch as a veritable sentient creature would. The degree of sensitiveness and movement varies.

Morren,[2] Brignoli, and other investigators observed that the ternate and quaternate leaves of several species of oxalis were sensitive and moved at high temperatures. Thus the leaves of the wood sorrel (*Oxalis Acetosella*), regarded by some as the true shamrock, were seen to move under the influence of heat and light; the movements being most marked in strong sunlight, and least marked when these conditions were absent. At night the three

[1] "Class-Book of Botany, being an Introduction to the Study of the Vegetable Kingdom," by J. H. Balfour, M.D., F.R.S.E., Professor of Medicine and Botany, University of Edinburgh.

[2] Morren, "Sur l'excitabilité et le mouvement des feuilles chez les Oxalis" (*Bulletin de l'Acad. Roy. de Bruxelles*, vi.; *Annales des Sc. Nat.*, 2nd ser. Bot. xiv. 350). Bruce, "Account of the Sensitive Qualities of *Averrhoa Carambola*" (*Phil. Trans.*, lxxv. 356).

PLATE CIV

Fig. 1.

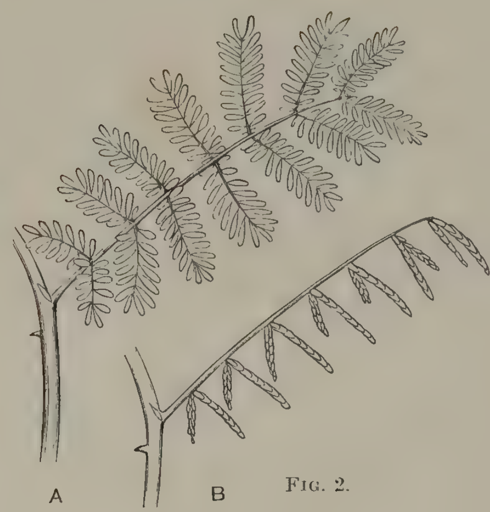


Fig. 2.

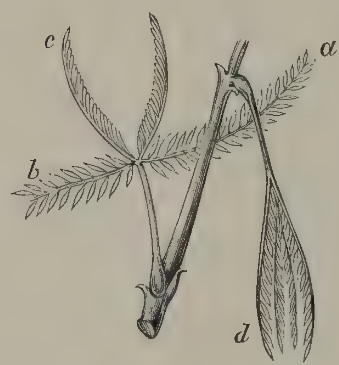


Fig. 3.

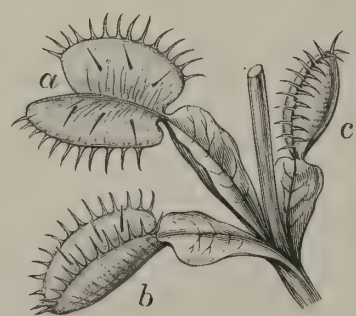


Fig. 4.

Fig. 5.

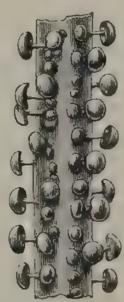


Fig. 6. × 7

leaflets which form the compound leaf of the plant were observed to fold on their midrib and then fall downwards in the direction of the common petiole or leaf-stalk.

Bruce [1] discovered similar properties in the pinnate leaves of *Biophytum sensitivum* and *Averrhoa Carambola*.

In the several kinds of oxalis at midday, when the sun shines strongly, the leaves are flat and horizontal and their margins touch. If, however, the leaf-stalk be gently and repeatedly tapped, or if the plant as a whole be excited, each leaf folds upon itself in a direction from below upwards; the leaf falling downwards. At night the leaflets close and remain closed. In the folded, drooping condition of the leaves the plant appears withered.

In *Mimosa pudica* and *sensitiva*—the sensitive plants proper—the leaf is a jointed, compound, bi-pinnate one, with four partial leaf-stalks springing from a common petiole or leaf-stalk.

The sleeping and waking of plants, and the movements of the sensitive and insectivorous plants, are illustrated at Plates civ. and cv.

[1] *Phil. Trans.*, lxxv. p. 356.

PLATE CIV

Plate civ. illustrates the waking and sleeping of plants, the folding and unfolding of the sensitive plant, and the opening, closing, and other movements of the insectivorous plants.

Fig. 1.—Shows the appearance presented by the leaves of *Cassia corymbosa* during the day and night from photographs. The figure to the left of the spectator represents the leaves in the waking condition, that to the right of the spectator the same leaves in the sleeping condition. The latter appear drooping and withered (after Darwin).

Fig. 2.—Shows the waking and sleeping appearance presented by the leaves of *Acacia farnesiana*. *a*, The leaf during the day; *b*, the same leaf during the night (after Darwin).

Fig. 3.—Shows branch and leaves, and the several movements occurring in the sensitive plant (*Mimosa pudica*) during the day and night, and when the plant is touched. At *a*, the petiole or leaf-stalk is in its erect state; at *d*, in its depressed state; at *b*, the leaflets are expanded; at *c*, they are closed. The erect leaf-stalk and expanded leaflets give the appearance of the plant during the day, while the folded leaf-stalk and closed leaflets give the appearance during the night, and when the plant is touched. The cellular swellings seen at the bases of the leaf-stalks and leaflets take part in these movements (after J. H. Balfour).

Fig. 4.—Stem and leaves of Venus's fly-trap (*Dionæa muscipula*) as figured by J. H. Balfour. The leaf consists of a blade with two portions connected by a hinge at a point corresponding with the midrib, and a petiole or leaf-stalk. The leaf, which when opened out as at *a*, presents a flattened appearance, is furnished along its four margins with a series of stiffish hairs, and in its central portions with six highly sensitive hairs with swellings at their bases. The sensitive hairs, when touched by small flies, beetles, &c., cause the two halves of the leaf to close and imprison them; the marginal hairs interlocking and making escape impossible. At *a*, the leaf is expanded and ready to receive prey; at *b*, it is partly closed and in the act of securing prey; at *c*, it is closed, the prey having become imprisoned. The leaf remains closed until the prey is crushed, digested, and assimilated. This done, the leaf gradually opens for a new supply. The fly-trap controls and regulates its own movements. If the plant is tricked by dropping non-edible particles upon its expanded leaf it closes, or partly closes, but does not remain closed (the Author).

Fig. 5.—Whorl of leaves of *Aldrovanda vesiculosa*. The aldrovanda has no roots, and floats freely in the water. The leaves are bi-lobed, concave, delicate, translucent, and protected by bristles which spring from the petioles or leaf-stalks. They open, according to Cohn, to the extent of the two halves of a living mussel-shell; the movement being considerably less than in Venus's fly-trap (Fig. 4, *a*). The two lobes of the leaves are unsymmetrical; the one being made more concave than the other. They are provided in their interior, concave, gland-bearing surfaces with numerous long, finely-pointed, flexible, sensitive hairs which, when touched by minute aquatic animals, cause the lobes of the leaves to close. The rims of the lobes are furnished with hair-like processes analogous to those found on the free margins of the leaves of Venus's fly-trap, and, no doubt, perform a like function, although this is doubted by Mr. Darwin. Aldrovanda captures its prey much in the same way as Venus's fly-trap, and the glands lining its bi-lobed, concave leaves provide what is virtually a digestive secretion (after Cohn).

Fig. 6.—Part of a leaf of *Drosophyllum lusitanicum* enlarged seven times. Shows under surface of leaf, which is linear, polished, concave above and convex below. The leaf is studded with a large number of glands resembling miniature mushrooms, which exude a viscid, acid secretion particularly attractive to small insects, which alight on the leaf and are captured by it. Other similar but smaller sessile glands also occur on the leaf. The secretion possesses solvent digestive properties, and the belief is that the plant is largely nourished by the insects caught by its leaves. This belief is strengthened by the plant possessing very small, inadequate roots. The drosophyllum in some respects resembles the sundew. It is not, however, provided with highly-sensitive, moving, hair-like tentacles. The plant, from the great number of insects captured by its leaves, is sometimes designated the fly-catcher (after Darwin).

PLATE CV

Plate cv. illustrates the appearance presented by the insectiverous plants, namely, the sundew and pitcher plant; also the glands of the former, the movements of its hair-like filaments or tentacles when seizing prey, and the clouding or staining which occurs in the substance of its leaf when digestion and absorption are going on.

Fig. 1.—Shows the shape of the leaf of the sundew (*Drosera rotundifolia*) and the appearance of the tentacles when at rest and in action.

A. Leaf of the sundew with its numerous long, tapering, highly sensitive hairs or tentacles, each terminating in a small oval swelling and tipped with a bleb of clear, viscid secretion very attractive to insects. Magnified four times; seen laterally.

B. Another leaf seen from above. Magnified four times. In A and B the tentacles are not in action.

C. In this figure a tiny speck of meat has been placed on the leaf, and the tentacles to the left of the spectator are seen bending and pressing it in the direction of the centre of the leaf.

D. In this figure all the tentacles are in action, due to the leaf having been immersed in a very weak solution of ammonia (one part to 87,500 of water). The leaf presents the appearance witnessed when an insect is caught and conveyed to its centre by the bending of the tentacles, where it is crushed and held firmly until the digestive secretion is exuded, and the act of digestion, absorption, and assimilation completed. The assimilation over, the tentacles gradually unbend and straighten and prepare to receive new prey (after Darwin).

Fig. 2.—Shows the clouding or staining of the leaf of the sundew during digestion (magnified twice).

A. Appearance presented by the leaf before feeding.

B. The same leaf five minutes after a small portion of dry proto-albuminose had been placed on it. The clouding or dark stain represents the position of the proto-albuminose; some of the tentacles are bending towards it.

C. The same leaf twenty-eight minutes after feeding. The proto-albuminose is partly dissolved, and the clouding or staining occasioned is spreading over the leaf and down the leaf-stalk. More of the tentacles are also bent.

D. The same leaf twenty-eight hours after feeding. The proto-albuminose is now largely dissolved, and the area of the clouding or staining of the leaf and leaf-stalk greatly enlarged. Absorption is evidently occurring. The number of tentacles bent is also increased (after Gillespie).

PLATE CV

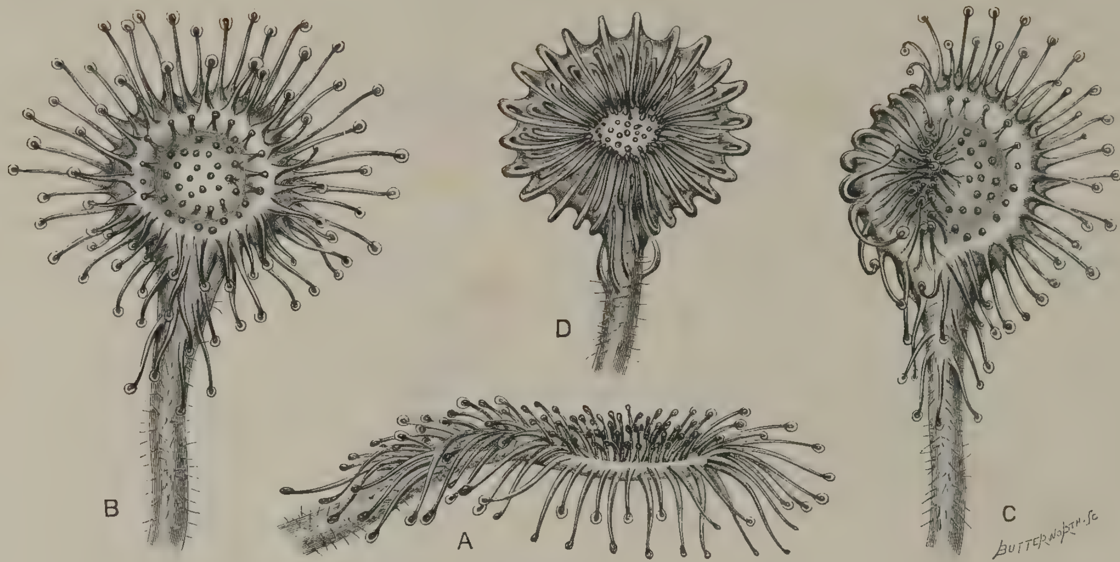


FIG. 1.

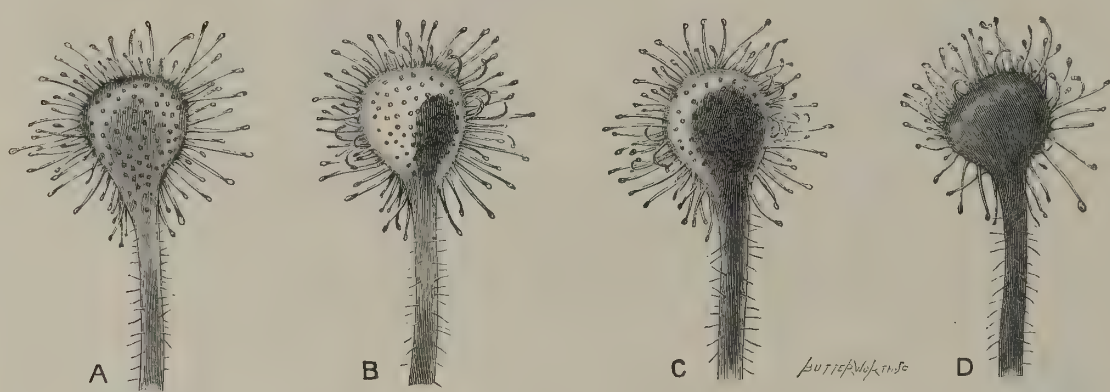


FIG. 2.

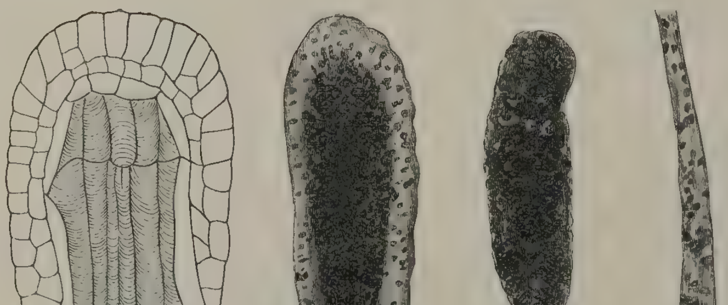


FIG 3.

FIG. 4.

FIG. 3.—Shows the structure and function of the oval-shaped terminal glands of the sensitive, hair-like tentacles of the sundew, very greatly magnified. The glands in nature only measure $\frac{1}{500}$ of an inch in length.

A. Longitudinal section of a gland consisting of two and in some cases three layers of polygonal, peripheral cells, enclosing a group of large, elongated, cylindrical, spiral cells. Spiral vessels and vascular tissues are also found in the gland. The elongated cells contain a limpid fluid, and are believed to communicate with the spiral vessels. The terminal glands secrete a clear, peculiarly viscid secretion resembling dew, which covers their exterior and attracts insects; hence the name sundew given to drosera. The terminal glands are highly sensitive, and there is reason to believe that they absorb as well as secrete. The hair-like processes or tentacles with their terminal glands play a chief part in the alluring and capturing of insects.

B. Terminal gland of an unfed plant grown in a weak solution of methylene blue, the blue having stained the nuclei of the outer or peripheral cells which invest the large elongated, cylindrical, spiral cells.

C, D. Terminal gland (C) and stem of tentacle (D) grown in a weak solution of methylene blue, to which a small quantity of proto-albuminose has been added. The cells of the terminal gland (C) and the aggregated masses of protoplasm in the stem (D) are deeply stained, showing the effects of absorption (after Gillespie).

FIG. 4.—Pitcher plant (*Nepenthes edwardsiana*), showing arrangements for capturing, digesting, and assimilating insects. The plant displays a series of flattened, elongated leaves, the midribs of which are extended and grow downwards (*c*); the midribs terminating in sack-like pitchers which grow upwards (*a*). The open mouth of each pitcher is surmounted by a lid (*b*). A very effective trap for securing small flies, beetles, &c., is thus provided. The flies and other minute living objects are attracted by the odour and juices of the pitcher, into which they creep. They are soon overpowered and sink to the bottom, where they are drowned and decompose, and are ultimately absorbed and assimilated, and so contribute to the nourishment of the plant (after Veitch).

The sensitive plants are provided with remarkable swellings at the bases of the petioles, partial petioles, and leaflets, which are intimately connected with their movements.

These swellings are composed of two sets of cells, one or other of which becomes turgid while the other contracts, and *vice versâ*, according to the degree and direction of the movements desiderated. The alternate turgescence and contraction of the cells referred to, which result in definitely co-ordinated and purpose-like movements, are due to vital changes. So long as the two sets of cells are of equal dimensions, the parts to be moved are in a state of equilibration: movements can only occur when the size of the cells on the one side of the part to be moved increases and that of the others diminishes; or when (the sizes of the cells remaining the same) the cells change shape in opposite directions; one set elongating when the other shortens, and *vice versâ*, as in the sarcous elements of muscles.

The leaves of the sensitive plant respond to light and darkness and to the slightest touch. They open during the day, and close at night and when touched. The leaflets or pinnules forming the leaves are expanded horizontally during the day. At night and when touched the leaflets fold upwards; their upper surfaces coming in contact. The leaf-stalk also becomes depressed, the whole leaf falling down and the plant looking dead. These points are illustrated at Plate civ., Fig. 3, *a*, *b*, *c*, *d*.

These movements occur every day and night so long as the plant lives, and is in a healthy condition. The curious feature in the movements is their responsiveness. In the presence of light the leaves open. They close in the darkness. When touched during the day the leaves close, but if left to themselves for a short time they open again. The plant distinguishes between day and night, and recognises the presence and absence of a foreign body. It has the power of spontaneously closing and opening its leaves.

De Candolle [1] performed some interesting experiments with sensitive plants. He exposed them for several days to abnormal conditions, namely light during the night, and darkness during the day. At first the opening and closing movements of the plants were very irregular. When, however, the plants became accustomed to the new conditions they acted more or less normally. Thus they opened their leaves in the evening (their time of light) and closed them in the morning (their time of darkness). When the plants were exposed to continued light they repeated their sleeping or closing, and waking or opening movements; these movements occurring at shorter intervals. When they were exposed to continual darkness the waking and sleeping movements became very irregular. The opening and closing movements, it will be seen, are not altogether dependent on the presence or absence of light; if they were so, the leaves would remain always open during the light, and be always closed during the darkness, which is not the case.

De Candolle found that the artificial light of six lamps induced the plants to open their leaves during the night.

M. Zantedeschi,[2] from experiments made by him at Florence, Padua, and Venice with *Mimosa ciliata*, *Mimosa pudica*, *Desmodium gyrans*, and other plants, came to the conclusion that the *lunar* rays affect the motions of sensitive plants, and that their movements are due rather to light than to heat. In moonlight at a temperature of 70° Fahrenheit, with Saussure's hygrometer indicating a medium condition of humidity, the leaf-stalks of *Mimosa ciliata* according to him were elevated $\frac{1}{5}$ of an inch, those of the *Mimosa pudica* $1\frac{1}{5}$ of an inch; the leaflets of *Desmodium gyrans* exhibiting distinct vibratory movements.

The movements of *Hedysarum* (*Desmodium*) *gyrans* are very remarkable. "The leaf is unequally pinnate,

[1] De Candolle, "Physiologie Végétale," ii. 860. "Memoire sur l'influence de la lumière artificielle sur les plantes" (Mém. de Savans Etrangers, i. 370).

[2] *Comptes Rendus* for October 1852, p. 523.

having a large leaflet or pinna at the extremity of the stalk, and two pairs of small pinnæ placed laterally. The large leaflet exhibits oscillatory lateral movements, as well as the ordinary sleep movements, in an upward and downward direction. During the day it rises, and appears to have slow motion from one side to the other, so that it often is seen in an oblique position as regards the stalk; during the night it is depressed and motionless. The little pinnæ, on the other hand, constantly exhibit a jerking motion, by which they first approach to each other, and then retire, the length of time required to complete their movements being about three minutes when the plant is vigorous and exposed to bright light. The leaflets exhibit motions even in darkness, although to a less extent. Other species of hedysarum exhibit similar movements."[1]

Zantedeschi and Hoffmann differ as to the causes which produce movements in the plants under consideration; the latter referring the sleeping and waking movements to temperature, light only influencing the phenomena in so far as it contains caloric rays, the former maintaining that even lunar rays affect the motions of sensitive plants, their movements not being due to the action of heat.

There are good grounds for believing that both authors are right up to a point. Heat and light are necessary conditions of plant life, and the movements of plants are always most vigorous when the plants are healthiest. There are, however, other factors besides heat and light to be taken into account, namely, life, original endowment, and ultimate function.

As has been shown in *Hedysarum* (*Desmodium*) *gyrans*, the movements are various, and cannot be traced wholly to either heat or light. Thus there are the ordinary waking and sleeping movements usually referred to light and darkness, and, in addition, oscillatory, lateral movements of the large leaf or pinna at the extremity of the stalk, and a constant jerking or rhythmic motion of the little pinnæ every three minutes. The leaflets, moreover, move in the dark, although to a less extent. The oscillatory and jerking movements are evidently vital in their nature; nor must the waking and sleeping movements of sensitive plants when exposed to *continuous* light, already referred to, be overlooked.

The manner in which the several parts of the sensitive plant respond to contact and stimuli is exceedingly interesting. If the two terminal leaflets be touched, or acted upon by heat or electricity, they fold upwards; the movement spreading to the other leaflets in succession from the apex to the base of the petiole. It also spreads to the neighbouring partial petiole, in which case the leaflets fold up in a reverse order, namely, from base to apex. When the basal leaflets are touched the foldings spread from the base to the apex of the petiole. When the middle leaflets are touched the foldings occur on either side. It follows that the movements spread from the point of contact. The movements are not confined to the leaflets; on the contrary, they extend to the partial petioles and the petioles likewise. Thus the partial petioles come together and close and the petioles fold down as seen at Plate civ., Fig. 3, *c*, *d*.

While the leaflets, partial petioles, and petioles are all affected, and respond to touch and stimulation, the stem of the sensitive plant is not influenced. The stem can be cut and injured in various ways without causing the folding movements referred to above. If, however, a mineral acid or a poison be administered to the stem and absorbed by the cells of the plant, the closing movements immediately supervene; the plant ultimately dying. Of course the poisoning of the stem of the plant at once destroys the normal action of its leaves.

Professor J. Y. Simpson[2] experimented on the sensitive plant with chloroform. He found that if the vapour was weak and applied for only a few minutes, the leaflets in certain cases closed, and did not expand again for an unusually protracted period. In other cases no closure occurred, and in a short time the plant became profoundly anæsthetised, so that stimulation of the leaflets and petioles failed to produce the ordinary movements. The sensitiveness of the plant only returned after a long interval. Professor Simpson likewise discovered that if sensitive plants were frequently anæsthetised they ceased to be sensitive; further, that if the vapour employed were too strong or too long applied the plant was destroyed.

Marcet[3] obtained somewhat similar results. He found that if one or two drops of chloroform be placed on the tip of a petiole the petiole drooped and the leaflets closed in succession from apex to base. The movement, moreover, spread to the other partial petioles and their leaflets. The leaflets in this case expanded subsequently, but were nearly insensible to touch.

The results obtained by the administration of chloroform to sensitive plants very closely resemble those obtained by the application of the vapour to man and animals. The plants are variously affected. Some close their leaves and act normally, others are apparently not affected at first and yet subsequently become profoundly anæsthetised. All, when under the influence of the vapour, cease to be sensitive; sensitiveness only returning after

[1] Nuttall, "Genera of North American Plants," ii. 110.
[2] *Edinburgh New Philosophical Journal*, xlvi. p. 295.
[3] "On the Action of Chloroform on the Sensitive Plant." (*Edinburgh New Philosophical Journal*, xlvi. p. 293.)

a protracted interval and in an impaired form. A parallel, it will be seen, may be drawn as to the effects produced by chloroform on plants, animals, and man. These effects, to say the least, are remarkable coincidences.

Other peculiarities are to be noticed. When sensitive plants are healthy and vigorous a puff of wind or general agitation occasions the simultaneous folding and depression of the leaves. If the agitation be repeated continuously for a short period, the plants become exhausted and do not respond. Precisely the same thing happens when muscles are similarly treated. Another curious point is that sensitive plants after a time become accustomed to gentle stimuli and cease to respond to them. Thus Desfontaines carried about a sensitive plant in a coach. At first the jolting of the coach caused the leaves to close. After a while, and when the plant had got accustomed to its new surroundings, its leaves opened. Here, as in animals, habit is second nature. *Sensitive plants respond to a great variety of influences*—light, darkness, vapours, gases, wind, rain, caustic fluids, heat, cauterisation, jolting, wounding, electricity, &c.

From the foregoing observations and experiments it appears that sensitive plants possess many of the attributes characteristic of sensitive animals, and that it is not possible to draw a sharp line of demarcation between them. The sensitive plants do not possess muscles and nerves in a differentiated form, but it is impossible to escape from the conclusion that they possess their analogues or representatives in an undifferentiated form.

The movements and general behaviour of the insectivorous plants are still more remarkable and inscrutable.

§ 189. Pitcher Plants.

In the case of the pitcher plant (*Nepenthes edwardsiana*), a veritable insect trap is provided, consisting of a curiously-modified pitcher-shaped leaf surmounted by a lid, as shown at Plate cv., Fig. 4.

The pitcher plant is furnished with scents, fluids, and gases which entice insects into its leaf chamber. Once there, they are narcotised, destroyed, digested, and ultimately assimilated. It is impossible to contemplate a pitcher plant without feeling that it is no chance product, and that it performs a certain rôle in the vegetable kingdom. It is fixed, and so cannot advance and seize the insects which form part of its pabulum, yet such is its shape, and such the properties of its solids, fluids, and gases, that flies and other small insects are attracted to it in large numbers, and find at once a lodging and a grave. In large pitcher plants it is no uncommon thing to find quite a handful of incarcerated insects. They are inveigled, caught, done to death, digested, and assimilated as perfectly as in the case of any conscious, intelligent animal. The *modus operandi* is briefly as follows: The insects, however attracted, enter the pitcher chamber in considerable numbers and continuously. When they reach the bottom of the pitcher they are overcome by gases and drowned. They then undergo a partial putrefactive process, and are acted upon by a ferment, akin to pancreatic juice, after which they are absorbed and assimilated. Professor S. H. Vines, in a communication to the Linnæan Society, points out that in the nepenthes the digestive ferment is not so much like that of the animal stomach as like that found in the pancreas or sweetbread. This latter organ furnishes a fluid which can digest all kinds of food, and one substance in its fluid—tripsin, to wit—acts specially on nitrogenous matter. It is this triptic principle which is represented in the pitcher plants, and Professor Vines inclines to think that it is also represented in other insect-eating plants.

THE DROSERACEÆ OR INSECTIVOROUS PLANTS PROPER

Akin in some respects to the pitcher plants is the family of the Droseraceæ so carefully and exhaustively described by Mr. Darwin.[1]

It embraces the following six genera: *Drosera rotundifolia* or common sundew, *Dionæa muscipula*, *Aldrovanda vesiculosa*, drosophyllum, roridula, and byblis.

The insectivorous plants have a wide range, and include a comparatively large number of species; the sundew, the most important member of the group, running to one hundred species or thereby, and being found both in the old and new worlds. It extends in the former from the Arctic regions to Southern India, the Cape of Good Hope, Madagascar, and Australia; in the latter from Canada to Tierra del Fuego.

Dionæa muscipula, the most highly differentiated of the order, includes only one species, and is confined to Carolina.

Aldrovanda vesiculosa ranges from Central Europe to Bengal and Australia. *Drosophyllum* (one species) is only found in Portugal and Morocco; *Roridula* (two species) in the Cape of Good Hope, and *Byblis* (two species) in Australia.

[1] "Insectivorous Plants," by Charles Darwin, M.A., F.R.S., &c. London, 1875.

The insectivorous plants have several features in common, and these are at once striking and important, as they confer on the vegetable kingdom powers whereby plants assume attributes formerly supposed to belong exclusively to animals.

Thus they are all more or less sensitive. They all capture live insects, which form a not inconsiderable portion of their food. Some of them produce a digesting fluid and ferment not unlike gastric juice; the insects being digested before being absorbed and assimilated. Others catch and absorb the insects after a partial putrefactive process has set in. All are provided with cells and hairs or tentacles on their leaves; the leaves being specially modified.

The leaves or parts of them are endowed with independent movements.

The roots are, for the most part, very scanty, and, in the case of *Aldrovanda vesiculosa*, altogether wanting; the plant floating freely about in water. The sparsity and absence of roots largely account for the remarkable modifications and higher functions assumed by the leaves (Plate civ., Fig. 5).

The manner in which the insectivorous plants capture insects is at once varied and interesting. In the case of drosophyllum, roridula, and byblis, this is effected by a viscid fluid secreted by their glands; in the case of drosera (Plate cv., Figs. 1, 2, and 3), by means of the viscid fluid, aided by the movements of the hairs or tentacles situated on the leaves; and in dionæa and aldrovanda (Plate civ., Figs. 4 and 5), by the closing of the blades of the leaf.

In dionæa and aldrovanda there is an absence of viscid secretion, which is compensated for by the sudden closure of the leaves which secure the living prey. The movements in aldrovanda are confined to the basal parts of the bi-lobed leaves; in dionæa the whole lobes (the spikes excepted) move; the movements being most marked in the vicinity of the midrib. In drosera, the principal movements occur at the bases of the hairs or tentacles; the whole blade of the leaf not unfrequently curving inwards, and so converting the leaf into a temporary stomach (Plate cv., Fig. 1, C, D; Fig. 2, B, C, D).

Mr. Darwin says, "There can hardly be a doubt that all the plants belonging to these six genera have the power of dissolving animal matter by the aid of their secretion, which contains an acid, together with a ferment almost identical in nature with pepsin; and that they afterwards absorb the matter they digest. . . . It is, no doubt, a surprising fact that a whole group of plants (and some other plants not allied to the Droseraceæ) should subsist partly by digesting animal matter, and partly by decomposing carbonic acid, instead of exclusively by this latter means, together with the absorption of matter from the soil by the aid of roots."

Mr. Darwin in this connection draws a parallel between the exalted function discharged by certain plants and the degraded function discharged by certain animals. Thus in 1875 he observes: "The rhizocephalous crustaceans do not feed like other animals by their mouths, for they are destitute of an alimentary canal; but they live by absorbing through root-like processes the juices of the animals on which they are parasitic." I had myself drawn a similar parallel three years prior to Mr. Darwin, namely, in 1872, as regards the human fœtus.

These examples of the degradation of animals and the elevation of plants in the scale of being show how difficult it is to draw a line of demarcation as between plants and animals. As science advances it becomes more and more clear that plants and animals have many things in common, and that, within limits, the plants overlap the animals.

Even the development of the fœtus in the highest animals is directly traceable to the existence of root-like processes (shaggy chorion and placenta) and the absorption through them of nutrient animal fluids (Plate xcii. Fig. 1, B, C, F, H, I, J, L, p. 396; Plate xcv., Figs. 1, 3, and 4, p. 407).

As I pointed out in 1872,[1] the fœtus *in utero* even in the genus homo is to all intents and purposes a parasite. The following is the account given by me at the date in question: "The relation which the fœtus bears to the mother is that which the plant bears to the ground and the air; and that which the tissues of the adult animal bear to its alimentary canal and lungs, through which it obtains its nourishment and its breath. The capillary or villous tufts of the fœtal portion of the placenta represent the roots of the plant; the corresponding capillary tufts of the maternal portion of the placenta, the ground and atmosphere on which the plant subsists. The fœtus is in this sense to be regarded as a parasite, for it is a living thing subsisting upon another living thing. This explains why a fœtus can take root and live upon other mucous surfaces than those supplied by the uterus, as, for example, those of the Fallopian tubes; and I can quite understand that the fœtus would thrive on certain portions of the mucous lining of the alimentary canal, if we could only succeed in making a natural transference."

I was induced to place the developing fœtus in the category of parasites from a careful study of the conditions under which development proceeds.

I recognised the fact that the impregnated human ovum (a living thing extruded from the ovary and carrying

[1] "The Physiology of the Circulation in Plants, in the Lower Animals and in Man," by the Author. *Edinburgh Medical Journal*, 1872–73; Macmillan, London, 1874, p. 125.

with it a certain amount of pabulum) found its way into the interior of the uterus; that it came merely in contact with a portion of the mucous lining of the uterus not specially prepared; that any mucous lining or surface (even outside the uterus) answered the purpose; that the apposition was to a large extent accidental and mechanical; that a process of osmose and absorption as between the ovum and the fluids supplied by the maternal mucous linings (uterine in normal pregnancy) was set up; that mere apposition and the heat and moisture provided by the uterus in the early stages only were required; that in the later stages root-like processes (shaggy chorion and fœtal portion of placenta) were given off by the ovum; that the fœtal root-like processes interdigitated and planted themselves between similar maternal processes developed on the uterine mucous lining (maternal portion of placenta); that by this means a most intimate but temporary osmotic union between the fœtus and parent was established, whereby the former was nourished and had its blood aërated; that the maternal portion of the placenta acted as a temporary stomach and lung to the fœtus; that the fœtus is in a sense outside the mother, a clear passage between it and the outer world being provided; that the junction between the fœtus and mother, although very intimate, is from the time of conception till the period of parturition of a temporary character; that the fœtus only adheres to the mucous lining of the uterus, and when the proper time arrives is shed as a leaf in autumn is shed; there being no detriment or hurt to either the fœtus or parent, provided the pregnancy be normal.

Everything connected with impregnation, conception, gestation, and parturition even in the higher animals is more or less vegetative in character, and vito-mechanical in its nature. The male and female elements come together and commingle, and the impregnated ovum in due time throws out roots by which it absorbs all the pabulum required for its future development.

If the fœtus be regarded as a parasite—a living something growing upon a living organism—from which it can separate at parturition without hurt to itself or its host, all the conditions of the fœtal state are fully and fairly met.

Mr. Darwin, as already stated, has shown how low animal forms with no mouth or alimentary canal, or with mouth and alimentary canal imperfectly developed, can live and grow by throwing out roots in all respects analogous to the roots of plants. The history of the developing ovum furnishes a still more important analogy. As a matter of fact, all the processes of absorption and assimilation in animals, as a class, may be referred to the presence of such simple contrivances. The villi of the alimentary canal, by the aid of which the prepared food passes direct into the lacteals and the blood-vessels and indirectly into the blood of the tissues, are mere roots resembling in many respects the roots of plants; molecular, cellular, and intercellular osmotic changes are referable to similar causes. It is more especially in the fundamental conditions of life that the plant and the animal occupy common ground. It may now be said, with something like accuracy, that the animal has its vegetative processes and functions, and that the vegetable has its animal processes and functions.

In the case of the developing fœtus a very perfect alimentary canal—nay more, all the important tissues and systems, even the vascular and nervous systems which constitute the most complex organisms (man included)—are the product of root-like vegetative processes planted in a suitable medium. The highest and lowest structures and the highest and lowest functions directly depend on simple, vito-mechanical arrangements.

It goes without saying that if the most complex tissues can be produced and the higher and highest functions can be discharged in such a simple manner, there is no reason why simple plant tissues (under guidance) may not differentiate and assume complex functions as in the insectivorous plants.

That there is differentiation in the insectivorous plants structurally and functionally is inferentially proved by their different behaviour under similar circumstances. Thus Venus's fly-trap responds to a slight *sudden* pressure and drosera to a *continued* pressure; some animal-feeding plants supply a digestive fluid which prepares the food for absorption; others absorb the food largely without preparation when it is merely liquefied by putrefactive processes; others combine the two processes.

In all these arrangements there are the most obvious examples of design, and the fact that plants can advance in the scale of being, while animals can degenerate structurally and functionally, shows that the trend in living things is not always or invariably upwards. The law seems rather to be that plants and animals (under guidance) modify themselves to make the most of their surroundings and the best of everything.

The insectivorous plants are the most sensitive and highly-differentiated plants known, and form most valuable connecting links between the vegetable and animal kingdoms. Their movements and functions clearly foreshadow the movements and functions of animals. They supply, so to speak, the stepping-stones which lead up to the more intricate and involved manifestations of life witnessed in the higher animals, not excluding man himself.

The insectivorous plants may be divided roughly into four kinds:—

(*a*) The pitcher plants and bladder plants, which trap their prey by means of variously-shaped vessels and cavities, with or without secretions.

(*b*) The butterworts, which partially close their leaves and so secure their victims; a digestive fluid being provided subsequently to the capture.

(*c*) The sundews, which attract and entangle their quarry by means of viscid secretions; specific movements and a special digestive fluid being provided to complete the capture and secure digestion and absorption.

(*d*) Plants which are not supplied with special chambers or cavities and are not endowed with spontaneous capturing movements, but which attract and secure insects by means of an exceedingly sticky secretion which is exuded on their surface and takes the place of bird-lime in bird-catching.

As there are some five hundred species of insectivorous plants, it is obvious that only a small number of the more representative ones can be dealt with in a work like the present.

It will be convenient at the outset to give examples illustrating the fourfold classification to which reference has been made.

Under the first group the pitcher and bladder plants fall to be considered.

The pitcher plants are to be found in large numbers in the conservatories of all botanical gardens. They are, as a rule, striking and graceful plants. Their delicately-tinted leaves are metamorphosed into the most marvellous and elegant shapes—some like an urn, some funnel-shaped, some like a pitcher; in fact, any shape which will serve as a trap for insects. It is well to note here that these wonderfully-shaped traps are not formed by the growing together of the edges of the blade of the leaf, as might naturally be supposed, but are formed almost entirely from the stalk, which has become flattened out. A part of the blade is usually represented by an expansion at the top of the pitcher, and it sometimes serves as a kind of lid on which the insects alight before entering the cavity beneath, which is to be their tomb. The inner wall in some is covered with sharp projections, all pointing downwards and overlapping like scales. It is the easiest thing in the world for any small animal to climb down the sides, but should it desire to return it is completely baffled, for it has to face an insurmountable obstacle in the piercing projections. Even if the insect possesses wings it is little better off, for when the liquid excretion is present in the pitcher it clogs them and renders them useless. The bladderworts are another very interesting species of carnivorous plants which belong to the first group. They are usually found growing in bogs, and they can often be seen in the summer floating about on the surface of the water. There are no true roots, and what might be taken by the casual observer for the roots are really the submerged stem and leaves. The stem itself is delicate and branching, and the leaves are curiously broken up into thread-like segments. From the stem there also arise little bladders, each of which possesses at its mouth a small valve which can be opened or closed. These bladders are of a very delicate green, and they are partially transparent. They are protected from the attack of large insects by a row of strong bristles round the mouth. From the lower lip of the mouth there projects into the bladder a sort of cushion, while the valve is attached to the upper lip, and hangs down so as to touch the cushion beneath. An insect, on entering, can lift the valve with ease, and when it is once inside the bladder, the valve falls back and rests upon the cushion as before. Then the animal may struggle as it likes, it cannot open the door of its prison, and must resign itself to inevitable death. Most animals die within twenty-four hours, though some live several days. Their death is due either to suffocation or to starvation. Gradually they decay, and the products of their putrefaction are absorbed by the specially-formed inner lining of the bladder.

To the second group, comprising those plants which perform definite movements, belongs the pinguicula, which is by no means uncommon in our own island. It displays a preference for damp and marshy soils, and is very commonly found growing in boggy ground. The common variety, *Pinguicula vulgaris* or butterwort, has a very beautiful little flower, violet in colour, and not at all unlike a violet in general appearance. The flower is supported on a long and slender stalk, which rises from a close rosette of leaves, growing almost flat on the ground. The leaves are somewhat oval and of a yellowish green colour, and they are remarkable in having the edge curved up so as to form a rim round the leaf. The upper surface is kept constantly covered by sticky secretion or mucilage. In consequence of this secretion, if any small particle touch the surface of the leaf it will stick to it, but it is a noteworthy fact that unless the substance is a nitrogenous one, mere contact has no effect. If, on the other hand, a small piece of meat or an insect is placed on the leaf, it appears to receive an immediate stimulus, the secretion becomes acid, and the leaf itself closes over and securely wraps up the nitrogenous substance, whether it be artificially placed there in the form of a piece of meat or brought there naturally by the alighting of an insect. Thus insects which chance to alight on butterwort leaves are first of all caught by their feet and wings becoming entangled in the sticky secretion. The leaf then slowly closes over them; the secretion becomes more plentiful and is also acid. Digestion of the soft fleshy parts goes on slowly but steadily, and at the end of two or three days the leaf expands again, bearing on its surface only the indigestible skeleton of its prey, all the soft part having been absorbed by the leaf. In butterwort the movement, though perfectly obvious, is slow, but in the case of the drosera or sundew the movement is much more rapid, and consequently more easily observed.

Venus's fly-trap (*Dionæa muscipula*) and the sundew (*Drosera rotundifolia*) afford good examples of the third group.

These plants are endowed with independent movements and provide digesting secretions.

The leaves in the fly-trap are arranged in a rosette round the flower stalk, and they are very curiously shaped. The stalk is broad, flat, and thin, very like the blade of an ordinary leaf. It expands at the top into the true leaf, which is rounded into two lobes, and the edges are deeply sculptured into jagged teeth. Each lobe also bears three exceedingly sensitive, stiff, hair-like processes which project from its interior. If the plant receives a shock there is no visible result, but where the upper surface is touched, the two lobes, normally at right angles to one another, now move as if mutually attracted until their edges meet and the teeth interlock. If an insect or other small animal happens to touch one of the six delicate hairs or spines, the lobes interlock with great rapidity, pressing upon the animal within and rapidly suffocating it. The upper surface of the leaf is covered with glands which pour forth a highly acid secretion: the soft parts of the animal are digested and finally absorbed. It generally takes several days for the leaves to expand again: sometimes so long a period as twenty days has been noted.

The sundew displays powers, in some respects even more extraordinary. This remarkable plant is found growing in damp localities, and is common in many high moorland districts. The leaves grow close to the ground and in the form of a rosette. From the edge and upper surface arise numerous delicate tentacles; those in the centre are green and short, but towards the edge they become much larger, and assume a deep red colour, and each bears on its tip a single glistening drop. As there are nearly two hundred of these exquisite little filaments, each with its shining miniature sphere, the whole leaf sparkles vividly in the sunlight, hence its name sundew. If the leaf merely receives some shock such as the buffeting of the wind, it exhibits no movement; nor if it is irritated by a non-nitrogenous substance does it give much sign, other than a more copious secretion of mucilage. If, however, an insect is unwary enough to trust itself on the leaf it is at once entangled, and first the tentacles immediately surrounding the spot bend slowly over, then, finally, every tentacle is curved over towards the centre of the leaf. The insect, of course, is hopelessly entrapped, and from the tip of the tentacles is poured the secretion which acts as a digestive fluid. The period of digestion varies according to the conditions, but generally takes from one to four hours. Then the tentacles resume their upright position, and only the skeleton of the immolated insect remains.

It is interesting to notice that in the case of the sundew the tentacles alone do the triple work of receiving the stimulus, seizing the prey, and digesting it; while in the case of the fly-trap the spines receive the stimulus, the lobes and teeth represent the seizing apparatus, and the glands on the surface are the structures subservient to the digestive process.

The fly-catcher (*Drosophyllum lusitanicum*) furnishes an illustration of the fourth or last group, where the plants catch and retain insects solely by means of a sticky secretion.

The fly-catcher is often used by the people of the districts where it is found growing as a means of clearing their houses of flies, when they are troublesome. It is found in Portugal and in Morocco, growing in rocky ground or on dry and sandy soil. It is a plant bearing a number of leaves rising direct from the root. The leaves are long and somewhat grass-like, and they are curved along their length, so that the upper surface is concave and the under convex. The under surface, which is, of course, in this case, the one more exposed, is covered with little beads that glisten like drops of dew. An insect, finding itself on one of these leaves, is not likely to escape without touching at least one drop, and probably entirely removing it. But this is of little avail, for the sticky drop so hampers and clogs the insect that it is soon helpless, and rolls further down the leaf, where it is acted upon by the digestive secretion. It is quite a common sight to see a leaf bearing at one and the same time animals but newly caught and alive and struggling, others which have just succumbed, and some which have been long dead and decayed. These examples are only a few typical ones out of the many that might be chosen, but they will suffice to show that just as there are animals which are essentially herbivorous, so there are plants which are essentially carnivorous.

In order fully to realise the special properties of, and powers exercised by, insectivorous plants it may be useful to deal with the more outstanding examples in detail and in a gradually ascending series. I will therefore discuss shortly, *Aldrovanda vesiculosa*, drosophyllum, roridula, and *Byblis gigantea* as leading up to the pitcher plants proper, and to Venus's fly-trap and the sundew, which are *par excellence* the highest representatives of their order.

§ 190. **Androvanda vesiculosa** is an aquatic, insectivorous plant, and bears a certain resemblance to *Dionæa muscipula*. It is provided with bi-lobed leaves which close when suddenly touched. These leaves occasionally contain bubbles of air, and look like little bladders, and hence the epithet *vesiculosa*. The plant has no roots, and floats freely about in the water. Its general appearance is given at Plate civ., Fig. 5.

The structure of the leaves deserves attention. They are disposed in whorls round the central axis or stem, and are composed of two concave portions, the one flatter than the other. These in securing and rejecting prey open and close like the shell of a bivalve. The leaves and petioles are provided with fine two-armed papillæ. The

leaves are cellular and furnished with glands. "On the concave gland-bearing portion of the lobes, and especially in the midrib, there are numerous, long, finely-pointed hairs, which, as Professor Cohn remarks, there can be little doubt are sensitive to a touch, and, when touched, cause the leaf to close. They are formed of two rows of cells, or according to Cohn, sometimes of four, and do not include any vascular tissue."

Cohn found many kinds of crustaceans and larvæ, and Stein water-insects, imprisoned within the bi-lobed leaves of aldrovanda. All these were doomed to certain death, there being no possible means of escape for them.

It is not quite determined whether aldrovanda secretes a digestive fluid, although from its resemblance to dionæa this is more than probable. It certainly has the power of absorbing animal substances either after digestion or consequent upon putrescent changes ; its power to entrap, seize, and assimilate small animals is indubitable.

Mr. Darwin gives it as his opinion that different portions of the leaves of aldrovanda perform different functions ; one part of a leaf being set apart for true digestion, another part of the same leaf for the absorption of decayed animal matter. This view involves a very great degree of structural and functional differentiation, which a consideration and study of the insectivorous plants as a whole enables us to understand.

§ 191. **Drosophyllum lusitanicum.**—This is a comparatively rare plant, found in Morocco and Portugal. In the latter country it is known as the "fly-catcher," from the very large number of insects which adhere to its leaves. It has, like other insectivorous plants, very small roots. Its leaves, which are linear and several inches in length, spring from a hard stem. They are concave above and convex below, with a narrow channel between. The upper and under surfaces of the leaves are covered (the channel excepted) by two sets of glands arranged on long and short pedicels longitudinally, having a pink or purple colour. The pedicels are to be regarded as the homologues of the hair-like processes or tentacles in other insectivorous plants. They differ from those of drosera in not being endowed with the power of moving. The glands resemble miniature toadstools, as shown at Plate civ., Fig. 6.

They exude a large quantity of acid, viscid secretion which is very attractive to insects. This secretion is poured forth spontaneously in anticipation of insects alighting on the plant, and is not the product of irritation induced by the presence of the insects. The pedicels or tentacles bearing the glands, as stated, do not move ; the insects being entangled in, and destroyed by, the viscid secretion alone. The dead insects are absorbed by the glands ; the glands performing the double function of secreting and absorbing.

As many as fifty insects or their remains may be seen on a small plant at once.

The glands, according to Mr. Darwin, "are formed of two layers of delicate angular cells, enclosing eight or ten larger cells with thicker, zigzag walls. Within these larger cells there are others marked by spiral lines, and apparently connected with the spiral vessels which run up the green multicellular pedicels."

In addition to the glands and long and short pedicels described, a large number of very tiny sessile glands can be detected. They occur on the upper and lower surfaces of the leaves, and are similar structurally to the others. They, however, differ in respect that they only secrete when insects are present. The secretion of the pedicelled toad-stool glands is primarily concerned in entangling and catching the insects, that of the lesser glands in digesting them. Both sets of glands, however, are engaged in absorbing and assimilating the insects when in a liquefied, disintegrating condition.

That the glands (with and without pedicels) absorb animal substances is clear from this : when such substances are presented to them the contents of the glands assume a very dark colour and become much aggregated. The outer cells of the glands before feeding contain limpid purple fluid, the inner ones rounded masses of purple granular matter. After feeding the glands assume a very dark and almost black colour, and their contents become aggregated in masses like small mulberries. Drosophyllum digests fibrin and albumen even more quickly than drosera.

The differentiation and division of labour as between the larger and smaller glands is deserving of attention. The fact that in a plant, one set of glands spontaneously pours forth an acid, viscid secretion to entangle and destroy flies, &c., in anticipation of their alighting upon it, and that a second set exudes digestive secretion when the insects are caught and present (both sets of glands having the power of absorbing animal substances), may well excite admiration and surprise ; admiration for the excellence of the arrangements of "means to ends," and surprise that in the vegetable kingdom functions in some respects as complex and diverse as those occurring in the animal kingdom are to be met with. In drosophyllum, and the insectivorous plants as a whole, the arrangements for catching, destroying, digesting, absorbing, and assimilating insects are of a high order, and in some cases very intricate in matters of detail.

Indeed the seizure and capture are, in a way, as perfect as if directed by intelligence, and the digestion cannot be said to differ materially from that which occurs in our own bodies. The key to the situation, and the only possible explanation, is that the First Cause (the origin, fount, and seat of all intelligence) works in and through the plants as it does in and through everything in the universe, whether organic or inorganic. It is futile to speak of plants exercising volition, acquiring habits, and working out their own destinies, as apart from design, guidance, and super-

vision. The lives of plants and animals are conditioned and adapted to their *environments*, but the plants, equally with the animals, are provided with the means of existence in the shape of suitable pabulum, and with organs and powers which enable them to secure and deal with that pabulum, whether organic or inorganic, whether solid, fluid, or gaseous, or partly the one and partly the other.

If plants and animals had to acquire habits, the formation of which involved their very existence, life would be a very precarious possession. Habit, in plants and animals, is a secondary consideration. It is not one of the fundamental factors of life. The life must be guaranteed before a habit can be formed. It would scarcely do for animals to have to learn to walk and run in order to catch food, and it would not be quite philosophical to require plants to develop habits in order to live.

The fact that the larger pedicelled glands in drosophyllum spontaneously exude, and in large quantities, an acid, viscid secretion which enables it to entangle and catch flies conclusively proves, it appears to me, original endowment and fitness, as apart from acquired habits, irritation, and *stimulation*. The plant lives because it is provided by nature at first hand with properties and powers and environments which enable it to live.

The plant does not fashion its own parts—leaves, glands, cells, roots, &c.—still less does it form the insects on which it preys, or the universe it inhabits.[1]

§ 192. **Roridula.**—Little has to be said regarding this plant further than that it is a native of the Cape of Good Hope, and bears a general resemblance to drosophyllum. Its leaves spring from a woody stem, and are linear and attenuated at their summits. They are concave above and below, with a ridge between, and covered with unicellular hairs and tentacles of variable size. The glands are supported on multicellular pedicels. The glands exude a large quantity of viscid secretion which, as in drosophyllum, catches insects in large quantity. Neither the tentacles nor pedicels, so far as is known, move.

§ 193. **Byblis gigantea** is a native of Western Australia, and in several respects resembles the drosophyllum and roridula. Thus the leaves spring from a strong stem, are some inches in length, linear, slightly flattened, with a projecting rib on the under surface, and covered with glands of two kinds; one set being provided with pedicels, a second set being sessile and arranged in rows. According to Mr. Darwin the glands are purplish, much flattened, and formed of a single layer of radiating cells, which in the larger glands are from forty to fifty in number. The pedicels consist of single elongated cells, with colourless, extremely delicate walls, marked with the finest intersecting spiral lines. As the pedicels of the glands do not move, and the pedicelled glands pour forth a viscid secretion, there can be little doubt that their function is to entangle and catch insects. The sessile glands provide the digestive secretion; both the sessile and non-sessile glands take part in the absorption and assimilation of the animal matters. That byblis is an insect-catching plant is evident from the comparatively large number of flies, &c., found on its leaves.

Mr. Darwin, with his usual industry and thoroughness, examined not only the hairs and glands of the insectivorous plants but also those of ordinary plants. He summarises the subject as under: "Species of saxifraga, primula, and pelargonium have the power of rapid absorption. . . . Their glands absorb matter from an infusion of raw meat, from solutions of the nitrate and carbonate of ammonia, and apparently from decayed insects. This was shown by the changed dull purple colour of the protoplasm within the cells of the glands, by its state of aggregation, and apparently by its more rapid spontaneous movements. The aggregating process spreads from the glands down the pedicels of the hairs; and we may assume that any matter which is absorbed ultimately reaches the tissues of the plant. On the other hand, the process travels up the hairs, whenever a surface is cut and exposed to a solution of the carbonate of ammonia. . . . The glandular hairs of ordinary plants have generally been considered by physiologists to serve only as secreting or excreting organs, but we now know that they have the power, at least in some cases, of absorbing both a solution and vapour of ammonia. As rain water contains a small percentage of ammonia, and the atmosphere a minute quantity of the carbonate, this power can hardly fail to be beneficial. Nor can the benefit be quite so insignificant as it might at first be thought, for a moderately fine plant of *Primula sinensis* bears the astonishing number of about two millions and a half of glandular hairs, all of which are able to absorb ammonia brought to them by the rain. It is moreover probable that the glands of some of the above-named plants obtain animal matter from the insects which are occasionally entangled by the viscid secretion."

§ 194. Dionæa muscipula or Venus's Fly-trap.

This is one of the most remarkable plants in existence, if regard be had to its movements and to its degree of differentiation structurally and functionally. It deserves a more than passing description. It is a true insecti-

[1] Mr. Darwin expresses an opposite view. He says, "As insects do not commonly adhere to the taller glands, but withdraw the secretion, we can see that there would be little use in their having acquired the habit of secreting copiously when stimulated, whereas with drosera this is of use, and the habit has been acquired. Nevertheless the glands of drosophyllum, without being stimulated, continually secrete, so as to replace the loss by evaporation."

vorous plant, and is specially constructed to seize and partially feed upon insects. A drawing of it is given at Plate civ., Fig. 4.

It is a native of North Carolina and grows in damp places. Like other insectivorous plants it has small roots, and these are believed not to supply moisture. It is stated by Mr. Knight that a plant of dionæa on the leaves of which " he laid fine filaments of raw beef was much more luxuriant in its growth than others not so treated."

The necessity for the leaves of the fly-trap being constructed to catch and digest insects becomes obvious. The dionæa is aggressive in the sense that it exhibits independent movements which play a conspicuous part in the capture of live prey. Its leaves move to given ends; the movements being co-ordinated and, within limits, preconcerted.

The fly-trap is admirably adapted to its peculiar mode of life. Thus each of its leaves is provided with a jointed blade having a strong, well-developed midrib; each half of the blade being furnished with a spiky or toothed margin, a large number of minute glands, and three highly-sensitive hairs, with bulbs or swellings at their base, as represented at Plate civ., Fig. 4.

The midrib of the leaf corresponds with the hinge or folding portion, and the spikes, each of which contains a bundle of spiral vessels, approach and interlock when the leaf is folded. When the lobes of the leaf come together they enclose a concave space, which is obliterated when prey is secured; the lobes, as it were, flattening against each other. The sensitive hairs, usually six in number (three on each lobe), vary occasionally. Their chief characteristic is their extreme sensitiveness to a passing touch, as manifested by the sudden closure of the lobes of the leaves.

The hairs or filaments of the lobes are composed of several rows of elongated cells containing a purplish fluid. They are conical-shaped, and about the twentieth of an inch in length. Occasionally they are bifid or trifid at the apex. At the base they are constricted, and provided with a joint which enables them to fold, and so escape harm when the leaf is closed and crushing insects.

The hairs are exquisitely sensitive throughout to momentary contact; a slight impact with even a slender hair being sufficient to cause the immediate closure of the lobes of the leaf. The fly-trap responds more readily to momentary impacts than the sundew (*Drosera rotundifolia*); the latter being most affected by continuous pressure.

While the hairs of the leaves and the surface of the leaf between the hairs are sensitive, the stalk of the leaf is, to all intents and purposes, insensitive. The leaf and its stalk, according to Dr. Burdon Sanderson, are pervaded by currents of electricity.[1]

The leaves of the fly-trap, which are green, display on their upper surfaces, the margins excepted, a large number of minute purplish glands; each gland being composed of twenty or more polygonal cells containing a purplish fluid. The glands perform a double function. They can at once secrete and absorb. The spiked projections on the margins of the split leaves fit into each other when the leaf is closed like the teeth of a rat-trap. This arrangement prevents lateral shifting of the two halves of the leaf when the leaf is securing and crushing prey. The spikes are so placed that none but the very smallest insects can escape.

It will be seen that the fly-trap is fully equipped for securing and dealing with live insects of all kinds. Its sensitive hairs or filaments apprise the plants of their presence, the lobes of the leaves with their spiked margins close upon and secure them; the glands on the upper surfaces of the leaves pour forth an acid secretion with a ferment, akin to gastric juice, which dissolves and digests them; the same glands absorbing and assimilating the digested mass. The process is briefly as follows. When a hapless insect alights or crawls on the expanded bi-lobed leaf it sooner or later comes in contact with one or other of the six highly-sensitive hairs, with the result that the two halves of the leaves quickly come together. The imprisonment, crushing, destruction, digestion, and assimilation of the insect is a mere question of time. There is no escape when once the leaf closes and the spiked margins lock or interdigitate. While the sensitive hairs are largely concerned in opening the leaves, they take next to no part in closing them.

There is a great difference between the closing and opening movements. The leaves when touched by an insect close suddenly. If the insect be caught, they remain closed for days until it is digested. While the leaves close suddenly they open very slowly. " The lobes remain closed for a much longer time when in contact with animal matter than when made to shut by a mere touch, or over objects not yielding soluble nutriment."

When a leaf closes upon anything edible it forms itself into a temporary stomach. If the substance yields ever so little animal matter the glands at once provide an acid secretion containing a ferment resembling the gastric juice of animals. Each leaf can seize, kill, and digest from two to four comparatively large insects, after which they wither, and cease to contribute to the nourishment of the plant.

[1] *Proceedings of the Royal Society*, vol. xxi., p. 495. *Nature*, 1874, pp. 105 and 127.

§ 195. The Sundew (*Drosera rotundifolia*).

This remarkable plant is, on the whole, the best representative of the insectivorous plants, and was studied with great care by Mr. Darwin, to whom we owe much of the information we possess regarding it (Fig. 221).

The sundew belongs to the order Droseraceæ, consisting of one hundred species or thereby, found in all parts of the globe excepting the Pacific Islands.

The sundew has small white flowers, flat, rounded, slightly concave leaves with numerous cells and sensitive glandular hairs or tentacles, and comparatively small roots.

The leaves, which in the British species are about the size of a sixpence, grow in a rosette close to the ground, and are of a peculiar carmine colour ; the hairs or tentacles on their surface, which number about two hundred, being of the same colour. The leaves spread out horizontally from the leaf-stalk ; the flower-stalk, which is single, shooting upwards from the centre of the leaves and displaying a considerable number of tiny, semi-closed, white flowers.

The sundew, for the most part, grows in marshy localities and moorlands where the soil is poor, and it depends largely for its subsistence on insects and animalcules caught by its leaves : these supplying the nitrogenous matters denied by the impoverished soil it frequents. It may be said to live much more by its leaves than its roots : the latter, as stated, being small and planted in a non-nutritious medium, their chief function being to supply the plant with water. It affords an outstanding example of a carnivorous plant. As some animals live largely on plants, so the sundew lives largely on animals. It only very occasionally deals with and absorbs vegetable matters. This is an astounding fact, and invests the anatomy and physiology of the sundew with a more than ordinary interest.

FIG. 221.
Sundew (*Drosera rotundifolia*).

The sundew derives its name from the glistening appearance presented by its leaves when the sun shines on them (Plate cv., Fig. 1, A, B).

It is found on examination that the glistening appearance, which is very characteristic, is due to the fact that each of the hairs or tentacles of each leaf (some two hundred in number) is supplied at its free extremity with a large drop of clear, viscid fluid, which sparkles in the light like a drop of dew. The clear, viscid fluid, which is exceedingly tenacious and can be drawn out in threads, is the product of oval-shaped glands (Plate cv., Fig. 3, A, B, C, D), situated at the free extremities of the hairs or tentacles ; the hairs being slender, flat, tapering structures terminating in bulbous expansions.

The oval glands produce the clear, viscid fluid and also act as absorbents—an arrangement similar to what occurs in the small intestine of mammals, where secreting glands and absorbents work side by side.

The clear, viscid fluid referred to performs a most important part in the economy of the plant, as it attracts large numbers of living insects, the legs and wings of which it clogs when they alight on the leaves, and so prevents their escape. The insects captured vary in size from a midge to a butterfly or even a dragon-fly. The same fate awaits small beetles, ants, and other creeping things which incautiously stray upon the leaves. The more the insects, and other living objects caught, struggle to free themselves, the more perilous the situation becomes, as their movements induce a greatly increased flow of the viscid fluid which is effecting their ruin. It is thought that the viscid fluid destroys the insects by closing up their tracheæ or respiratory passages and so suffocating them.

The hairs or tentacles, glands, and the viscid secretion are parts of a designed whole. They form a cunningly-contrived living trap for securing animal food to the plant : not only so, the trap, in addition to being a living, self-acting trap, is a baited trap. The clear, viscid secretion supplied by the glands of the hairs provides the bait, and, in large measure, effects the capture. The hairs or tentacles of the leaf complete the capturing process, as they are endowed with independent spontaneous movements which enable them to curve towards and upon the insect to be secured and immolated (Plate cv., Fig. 1, C, D). They can even, by co-ordinated rolling movements, transfer the insect to the middle of the leaf ; the leaf, when the insect is large, becoming concave to receive and accommodate it. The leaf, as a matter of fact, converts itself into a temporary stomach.

The hairs or tentacles of the sundew are exceedingly sensitive, unequal in size, and consist of three sets : (*a*) those which stand up from the middle of the leaf and are shortest ; (*b*) those which radiate from the edge of the leaf and are longest ; and (*c*) those which occupy an intermediate position and are medium sized (Plate cv., Fig. 1, A).

The hairs or tentacles, as indicated, are thin, flattened, more or less straight, hair-like, slightly-conical processes.

terminating in a bulbous expansion which contains an oval-shaped gland. They consist of several rows of elongated cells filled with a purple fluid or granular matter, and are provided with spiral vessels and vascular tissue from the blade of the leaf, which run through them to the glands at their summits or free extremities.

The oval-shaped glands situated in the bulbous expansions of the hairs or tentacles are about $\frac{1}{500}$ of an inch in length, and are important structures from the fact that they secrete and absorb and are acted upon by foreign substances, especially organic nitrogenous ones. They consist of three outer layers of cells; these being polygonal, quadrate, and elongated, and containing purple granular matter. Within these is a group of elongated, cylindrical cells of unequal lengths closely packed together and invested with a spiral fibre which can be unravelled (Plate cv., Fig. 3, A). These are filled with a limpid fluid, and there is reason to believe they are connected with the spiral vessels which run through the hairs or tentacles.

The oval-shaped glands are exceedingly sensitive, so much so that they are affected by coming in contact with an extraordinarily weak solution of phosphate of ammonia (one part to 87,000 of water).

It is necessary to describe more or less minutely the structure of the glands and hairs of the sundew, as they are the chief factors in its wonderful economy. The glands give notice to the plant that insects have lighted upon it: they also supply secretions for entangling and digesting them. Finally, they act as absorbents. They set in motion (by what Mr. Darwin regards as reflex action) the hairs or tentacles, which curve or bend at their bases and assist in the capture and destruction of the insects. The employment of the term "reflex action" in this connection is unfortunate. That term in modern physiology is, strictly speaking, applied to animals with a nervous system, nerve centres, and sensory and motor nerves. It is not applicable to plants which are void of nerves in the ordinary sense. Plants, no doubt, possess equivalent structures in an undifferentiated form which enable them to feel and to act, in a sense, intelligently; but the transference of the nomenclature of animals with a nervous system to plants without a nervous system can only introduce confusion. Moreover, and as I point out elsewhere in the present work (*vide* section, "Reflex Action, Instinct, and Reason"), the term reflex action is of doubtful application in many cases, even as applied to animals. Reflex action, as applied to the peculiar movements of the hairs or tentacles of the sundew, does not explain all the circumstances of the case, for it is obvious that if a living insect supplied the stimulus which caused the hairs to bend, it could not, when dead, digested, and absorbed, furnish the stimulus to cause them to unbend and straighten. The bending and unbending movements are, it appears to me, in no way reflex in character. They are, on the contrary, spontaneous, independent, inherent movements, centripetal and centrifugal and rhythmic in their nature. They are necessary to the existence of the plant in the same sense that the cardiac and respiratory movements are necessary to the existence of the higher animals. The cardiac movements are not due to the supposed stimulus produced by the contact of blood with the interior of the heart; neither are the respiratory movements due to the contact of air with the interior of the lungs.

The highly-sensitive moving hairs possess a certain amount of discriminating power. Thus, if two insects are caught on the same leaf the hairs move towards them in two groups and both are secured. The hairs, moreover, are not set in motion by everything which touches them. They are not affected by puffs of wind, or by rain dashing against them, or by floating grains of sand. The instant, however, an insect, or something edible and nitrogenous, comes in contact with them, they become excited and active, and bend over and transfer the edible particle to the centre of the leaf, where it is firmly pinned down in from ten to twenty minutes. Mr. Darwin states, "I have distinctly seen, through a lens, a tentacle beginning to bend in ten seconds after an object had been placed on its gland: and I have often seen strongly pronounced inflection in under one minute."

Nor does what is an obvious sequence of events terminate here. As soon as the living or dead animal particle is securely fixed, an *acid* secretion (mark, acid—the nature of the secretion is changed, and is supplied in greater quantity at this stage) similar to the gastric juice of our own stomachs is exuded by the central and other glands, and the particle is digested and subsequently absorbed and assimilated; that is, incorporated with the substance of the plant (Plate cv., Fig. 2, A, B, C, D, p. 590).

Mr. Darwin asserts that the change in the quality and quantity of the secretion referred to occurs even before the object on the centre of the leaf has touched or come in contact with the glands, which can only mean that the glands furnish the acid secretion independently and in anticipation of the digestive process. There can be no reflex action here. The act is direct and pre-arranged, and an obvious "means to ends."

The viscid secretion prepared by the glands for attracting and entangling insects is neutral or very slightly acid: it becomes markedly acid when the insects are to be digested and absorbed. "The glands of the sundew secrete some ferment analogous to pepsin, which in presence of an acid gives to the secretion its power of dissolving albuminous compounds. There is a remarkable accordance in the power of digestion between the gastric juice of animals with its pepsin and hydrochloric acid and the secretion of drosera with its ferment and acid belonging to the acetic series. We can, therefore, hardly doubt that the ferment in both cases is closely similar, if not identi-

cally the same. That a plant and an animal should pour forth the same, or nearly the same, complex secretion, adapted for the same purpose of digestion, is a new and wonderful fact in physiology."

Not until the digestion and assimilation are effected do the sensitive hairs relax and let go their hold. When both are over, and after an interval of from one to four or five days according to the vigour of the plant, the temperature, and magnitude of the last meal, the leaf opens out, the hairs straighten, and their bulb-shaped extremities are furnished with a fresh supply of clear, viscid secretion. The trap is baited a second time, to secure a fresh supply of nitrogenous food. These tactics are repeated so long as the plant lives and is in a healthy condition.

A careful examination of the leaves with a lens always reveals traces of the last insect sacrificed, in the shape of wings, compound eyes, jaws, leg bones, claws, and other parts of the victim. The time occupied by the capture, digestion, and assimilation varies according to the size of the insect or animal to be dealt with, and the vigour and condition of the plant in relation to a former meal. If the insect be small and the plant active, two days suffice if large, a slightly longer time is required.

The remarkable discriminating power possessed by the sundew is shown in the different treatment accorded to edible and non-edible particles. If the particle be a living insect containing nitrogenous matter, the hairs do not relax their grip for two or more days : that is, not before it is killed, digested, and assimilated. If the sundew has been tricked, and the folding of its hairs caused by dropping a non-edible particle (a piece of hair, glass, cork, wood, &c.) on them, they unbend within a few hours, and no acid digesting juice is thrown over it. These diametrically opposite movements cannot be regarded as reflex in their nature. A double act of discernment is witnessed : (*a*) the hairs spontaneously unbend and straighten ; and (*b*) the digesting secretion is withheld. The digestive and assimilative processes are accompanied by most extraordinary changes occurring in the leaves and glands. At first a dark stain or clouding makes its appearance in the vicinity of the insect captured, and this spreads until the greater part of the leaf and stem are discoloured, as seen at B, C, D of Fig. 2, Plate cv., p. 590. This staining and clouding satisfactorily proves that the leaves and glands absorb.

Not the least interesting feature of the acid secretion supplied by the glands of the sundew is its antiseptic properties. "It checks the appearance of mould and infusoria, thus preventing for a time the discoloration and decay of such substances as the white of an egg, cheese, &c. It therefore acts like the gastric juice of the higher animals, which is known to arrest putrefaction by destroying the microzymes."

I know of no more fascinating study than that of the insectivorous plants as a class, and never lose an opportunity of examining them not only in the open but also under glass. The more extended my observations and the more minute my inquiries, the more have I been struck with the extraordinary adaptations which they display to their surroundings and habitats. I kept sundews for several years as pets, and was never tired watching their more than animal tactics in securing living prey. The plants, somehow, always contrived to have a full larder.

Mr. Darwin has directed attention to the peculiarities of the movements in Venus's fly-trap (*Dionæa muscipula*) and the sundew (*Drosera rotundifolia*) respectively. He says, "Although the filaments (hairs) of the fly-trap are so sensitive to a momentary and delicate touch, they are far less sensitive than the glands of the sundew to prolonged pressure. Several times I succeeded in placing on the tip of a filament of dionæa, by the aid of a needle moved with extreme slowness, bits of rather thick human hair, and these did not excite movement, although they were more than ten times as long as those which caused the tentacles of drosera to bend ; and although in this latter case they were largely supported by the dense secretion. On the other hand, the glands of drosera may be struck with a needle or any hard object once, twice, or even thrice, with considerable force, and no movement ensues. This singular difference in the nature of the sensitiveness of the filaments of dionæa and of the glands of drosera evidently stands in relation to the habits of the two plants. If a minute insect alights with its delicate feet on the glands of drosera, it is caught by the viscid secretion, and the slight though prolonged pressure gives notice of the presence of prey, which is secured by the slow bending of the tentacles. On the other hand, the sensitive filaments of dionæa are not viscid, and the capture of insects can be assured only by their sensitiveness to a momentary touch, followed by the rapid closure of the lobes. . . . There is a great contrast between drosera and dionæa in the effects produced by mechanical irritation on the one hand, and the absorption of animal matter on the other. Particles of glass placed on the glands of the exterior tentacles of drosera excite movement within nearly the same time as do particles of meat, the latter being rather the most efficient ; but when the glands of the disc have bits of meat given them, they transmit a motor impulse to the exterior tentacles much more quickly than do those glands when bearing inorganic particles, or when irritated by repeated touches. On the other hand, with dionæa, touching the filaments excites incomparably quicker movement than the absorption of animal matter by the glands. Nevertheless, in certain cases, this latter stimulus is the more powerful of the two." It will be observed that Mr. Darwin here speaks of a *motor impulse* in drosera, as if that plant possessed a nervous system, ganglia, and an equipment of sensory and motor nerves, which, of course, it does not.

From experiments made by Mr. Darwin there is reason to believe that the sensitive hairs or filaments of Venus's fly-trap are not glandular and do not absorb, in which respects they differ from the minute glands found in large numbers on the surfaces of the leaves. He inferred this from the application of a weak solution of carbonate of ammonia (one part to 146 of water) to them. When, however, a small portion of a leaf with a sensitive hair attached to it was cut off and immersed in the same solution, the fluid in the basal cells became quickly aggregated into purplish or transparent, irregularly-shaped masses; the aggregation travelling up the hairs to their tips, the opposite of what happens in drosera when its glands are acted on. Continued immersion in distilled water produced a like result. It is no uncommon occurrence to find some of the terminal cells of a hair in a spontaneously aggregated condition. Most remarkable of all, as Mr. Darwin points out, "the aggregated masses undergo incessant slow changes of form, uniting and again separating; and some of them apparently revolve round their own axes. A current of colourless granular protoplasm could also be seen travelling round the walls of the cells.[1] This current ceases to be visible as soon as the contents are well aggregated; but it probably still continues, though no longer visible, owing to all the granules in the flowing layer having become united with the central masses. In all these respects the filaments of dionæa behave exactly like the tentacles of drosera."

The sensitive hairs or filaments of Venus's fly-trap are highly specialised and important structures.

They are not affected by drops of rain or gusts of wind. They are indifferent to the contact of simple fluids. They are influenced only by the sudden contact of solid particles, and especially by living, edible particles, such as insects.

The fly-trap distinguishes between wind, rain, and solids. It also distinguishes between solids themselves. Thus, if bits of perfectly dry meat, albumen, or gelatine be placed on the leaves, the leaves do not move and the glands do not secrete. If, however, the same meat, albumen, or gelatine be made damp and their peculiar properties exploited, the leaf closes slowly and the glands pour out an acid secretion plus a ferment. The closure in such cases is deliberate, and differs from that produced by slightly touching the sensitive hairs. In the latter case, the closing is much more rapid. Only the glands in contact with the meat, albumen, or gelatine secrete to begin with; the area of secretion extending as digestion proceeds and the edible substances are broken down and dissolved.

Secretion and digestion proceed most rapidly when the leaves are firmly closed, as then the glands on each half of the leaf are at work.

Curiously enough, the surfaces of the leaves which are very slightly sensitive become more sensitive as the secretion is poured forth. The quantity of the secretion varies according to the amount of digestion to be performed. When a large insect is to be negotiated, the secretion is so plentiful as sometimes to escape from between the closed leaves. In such cases, the cells of the numerous glands on the surface of the leaves become aggregated into purple or colourless masses of protoplasm; the protoplasm slowly and continually changing its form, occasionally separating and re-uniting.

Damp, nitrogenous, organic substances elicit the maximum of closure and secretion. The plant is especially constructed to deal with them. Bits of cork, stone, glass, wood, paper, &c., produce neither closure nor secretion, and if, by chance, closure does occur, the secretion is invariably withheld.

The fly-trap exercises extraordinary powers. It only closes upon certain substances, and its secretions are reserved for edible particles, living or dead. It behaves exactly as an animal would, under similar circumstances.

The movements of the aggregated cell masses are very remarkable, as they indicate vital changes of an important character. The movements of aggregation in some respects resemble those of the pigment grains in the skin of the frog, first described by Lord Lister.

It is not necessary to pursue this subject further; suffice it to say, that Venus's fly-trap and the sundew provide examples of prescience and design which are profoundly impressive. How these plants, which have no nervous or directive system, can, nevertheless, act as several of the higher animals do, can only be explained by the Creator working in and through them. They could never have acquired the remarkable powers they display apart from a Creator, Designer, and Upholder. They act deliberately and to given ends. Their movements are, in no sense, accidental or haphazard. They entice, circumvent, and destroy in large numbers animals much higher in the scale of being than themselves. This they can only do by the exercise of inherent powers conferred upon them by an all-sufficient First Cause. They could not possibly have acquired these powers by any efforts put forth by themselves, however long the time allowed. Their existence and mode of behaviour are absolutely inscrutable apart from a Designer, Framer, and Upholder of the Universe.

[1] Similar movements of cell contents occur in many plants, as witness the gyration of protoplasm in the intra-cellular circulation.

SENSITIVE MOVING PLANTS: SPIRAL CLIMBING PLANTS: REVOLVING AND TWISTING STEMS, TENDRILS, LEAVES, &c.

The heading of this section suggests, and naturally raises, a question of great importance in the present inquiry, namely, Can plants and parts of plants feel and move, and if so, can they move in given directions and to definite ends? Modern science unhesitatingly answers in the affirmative. A living plant moves in all its parts and particles, and in the more highly differentiated plants, such as the climbing plants, sensitive plants, pitcher plants, insectivorous plants, &c., they display a low form of cognition and act as a rudimentary intelligence would suggest.[1] The highest plants are even on a more elevated platform than the lowest animals.

The sensitive plant responds to the touch; the pitcher plant inveigles insects into its scented, cool, but deadly chamber; Venus's fly-trap spreads its dainty leaves as the happy hunting-ground for tiny living things which it immolates; and the sundew baits the amazingly sensitive hairs on its leaves with a glittering, viscid secretion which attracts and ensnares myriads of small living creatures which, when caught, are overpowered, killed, and digested by a secretion akin to gastric juice. The sundew has been known to catch and devour small butterflies and even dragon flies. That a plant—a mere plant—should achieve such extraordinary results is difficult of realisation, but there is no disputing the facts.

Time was when it was vaguely asserted that plants were distinguished from animals by not having the power of movement. All that is changed now, and it becomes a question, and a serious one, whether plants are not provided with a semi-fluid, diffuse nervous system. That they are sensitive and feel is beyond doubt, and that their movements are purpose-like and pre-arranged is equally certain. Plants, like animals, have a great mission to perform, and they perform it independently—that is, they are not influenced to any considerable extent by their surroundings.

The functions performed by quite a large number of plants necessitate a nervous system or its equivalent. That the said system has not assumed a visible form and cannot be detected by the eye or re-agents is no proof of its non-existence. The same may be said of all force, and of electricity in particular. Forces are known only by the effects they produce, and if plants perform many of the functions performed by animals which are provided with rudimentary or complex nervous systems, it is reasonable to conclude that they possess a nervous system, or a controlling agency, of a kind. The argument now employed is virtually that advanced in other departments of physiology. It is not possible, for instance, to detect with the unaided eye, or with the assistance of the microscope, any difference in ultimate composition between the several impregnated ova of animals; yet one ovum produces an elephant, a second a crocodile, a third a bird, a fourth a man. All ova are, unquestionably, different *even as ova.* This goes without saying. The matter is one of pure reason.

If plants can feel and move to definite ends (and this is now generally admitted), and if they are sensitive and respond to the touch, much in the same way that animals do, there is no halting-place: a nervous system, or its equivalent, must be predicated. If, moreover, the several kinds of plants, and the various parts of the same plant, exhibit different degrees of sensitiveness, it follows that there is functional differentiation as regards their power of feeling. The same holds true of the sensitiveness of our own bodies; some parts are more sensitive than others. If, finally, sensitiveness is a proof of the possession of a nervous system, then the insectivorous plants, such as the sundew, unquestionably possess it, for their delicate tactile hairs and glands display a degree of sensitiveness which is not approached, far less equalled, by any part of the human body. The glands of the sundew, according to Mr. Darwin, appreciate and are set in motion by a speck of human hair measuring $\frac{8}{1000}$ of an inch in length, and weighing only $\frac{1}{78740}$ of a grain. "Moreover, far less than the millionth of a grain of ammonia in solution, when absorbed by a gland, acts on it and induces movement."[2]

The movements in plants greatly resemble those in animals. They occur at irregular intervals in both cases, the time of their occurrence and the duration thereof not being well marked. When plants and animals, or parts thereof, move at regular intervals with periods of rest between, the movements are designated rhythmic movements. We have good examples of rhythms in certain plants (the *Volvox globator*, for example), and in animals in the heart and hollow viscera generally.

[1] I recognise the difficulty and even the danger of employing the term cognition in the present connection, as it may be taken to imply perception in its extended sense, understanding, judgment, and even consciousness. Instinct, however, is inadequate to explain the facts, and is, moreover, an objectionable term. Of course there are two ways of looking at this subject. The Divine agency, or First Cause, may be regarded as working in the plant and directing all its movements, and supervising the due discharge of all its functions; or the plant may be regarded as endowed by its Maker with plenary powers which take the place of cognition in animals, and enable it to maintain its place in nature. What modern science has to recognise is, that plants and animals, from the lowest to the highest, are capable of looking after themselves, that they are not accidental formations with chance lives and uncertain destinies, but things formed to achieve certain results, which they invariably do achieve after their own peculiar fashion, and independently. It is not words we bave to deal with but facts.

[2] "Insectivorous Plants," by Charles Darwin, M.A., F.R.S., &c. London, 1875, pp. 32 and 33.

Plants, like animals, respire. Like them, they can be fed on healthy food and live, or they may be fed on poisoned food and die.

Plants grope about in space in search of substances useful to them, and in so doing they not unfrequently exert a selective power. Thus the roots of trees in stony regions avoid the rock and insert themselves into every crevice where there is soil. The roots of trees, in exposed situations, are more developed on the one side than on the other, the strongest roots being found on the side of the tree from which the prevailing wind comes; in which situation they act as supporting stays. Creeping plants, like the ivy and ampelopsis, develop rootlets and suckers which enable them to adhere to vertical supports; some employ hooks for the purpose; some (the nasturtiums, for example) climb and fix themselves by throwing their petioles or leaf-stalks round supports of various kinds, or by forming curious crooked bends which act like hooks; others twist their stems and twine round each other or round neighbouring plants or trees; others produce sensitive tendrils, by the aid of which they seize and are supported by structures stronger than themselves. All these adaptations imply a First Cause and Design.

The object in each case is additional support; the plants which have been provided by nature with only feeble stems seeking to raise themselves from the ground and rear their branches, leaves, flowers, and fruit into the sunlight and the air, which, in many cases, is no easy matter, where, as in tropical forests, there are tall trees and a thick undergrowth of scrub. The climbing arrangements are illustrated by a series of original figures at Plates cvi., cvii., cviii., and cix.

It is a beautiful sight to see a growing, sensitive, revolving stem or tendril circling about in space in search of a supporting structure, or a subterranean root, which by some mischance has become exposed to the air and light, doubling back in search of soil and darkness. The several modifications of plant structures in pursuit of a common object all point to inherent, independent powers in the plants themselves, which, it appears to me, are neither sufficiently understood nor appreciated, but which open up a long vista of profitable inquiry for future investigators.

The nature of growth, for example, on which form, structure, and function mainly depend, has never been properly defined in modern physiology. It is necessary, however, to refer to it briefly in discussing the spiral formations and movements of plants and animals. Growth, in the organic kingdom, is directly the outcome or product of life. It exerts a double power:—

(*a*) A power by which it attracts or draws into the living plant or animal the extraneous substances necessary to their production and development, whether gases, fluids, or solids;

(*b*) A power by which it forces plants and animals, or parts thereof, against substances which form no part of their own bodies, but which are useful to them.

Growth is a vital process, regulated by laws, and subordinated to the requirements of the individual, and the functions to be discharged by it. Growth is always accompanied by an increase of substance, and the increase may occur in all directions, or in particular directions. It also (and this is important) exerts a well-defined power in one or more directions. It is in every instance aggressive; in fact, it is primarily and essentially a pushing power.

Hales showed this long ago in the case of a forced, rapidly-growing vine, which exerted quite an extraordinary degree of pressure, which could be accurately measured. The force exerted by the roots of growing trees is sufficient to drive down strong, carefully-built stone walls, and to bend, twist, and even wrench out, iron stanchions from their fixings.

By growth, directed and controlled by a First Cause and life, plants are enabled to press themselves against, and fix themselves to, extraneous supports. This is true of the ivy with its rootlets, the ampelopsis with its suckers, and the great variety of climbing plants which wind spirally round vertical supports, or raise and fix themselves by spiral tendrils, or by the aid of hooks, or curved leaf-stalks, or midribs. In all these instances, the plant seizes and appropriates the supports. The supports have no power to approach and seize the plant. It is not a mere question of irritability and contact with foreign living and non-living bodies which act as stimuli. The supports do not produce the movements of the plant. This is proved by the fact that a climbing plant will twist on its own axis and revolve when no support is present, or when it has outgrown its support, as shown at Plate cix., Fig. 2. In such cases the revolving twining shoots rear themselves into the air without extraneous aids like living snakes.

It is further proved by the fact, that certain tendrils will coil themselves up into single and double reversing spirals in the air when they have not come in contact with extraneous matter of any kind; the spirals so formed having, in many cases, precisely the same outlines as the spirals formed by the tendrils which have seized a support (Plate x., Figs. 1 and 2; Plate cvii., Figs. 1 and 2). This happens in the passion flower (*Passiflora quadrangularis*) and also in the hop (*Humulus Lupulus*). The same holds true of leaf-climbing plants (Plate cvi., Fig. 1, E). The leaf-stalk becomes bent and kinked in anticipation of coming into contact with a support. This is seen in *Tropæolum minus*. Moreover, the elongated midrib of the leaf in leaf-climbers, if it does not lay hold of a support, coils up into a most exquisite spiral whorl, as seen in *Gloriosa superba* (Plate cvi., Fig. 1, B).

The spiral coils to which allusion has been made may be conveniently divided into two kinds :—

(*a*) The typical or fundamental terminal spiral coil completed without contact with a foreign body ; and

(*b*) The physiological or functional spiral coil modified, but not caused, by contact.

The latter may or may not coincide in shape with the typical terminal spiral coil. There is this difference : the typical terminal spiral coil is more slowly formed than the physiological or functional one. The latter is the quick-moving lasso thrown round the support to seize, capture, and make the support useful for the purposes of the plant, whose stem is too weak to enable it to grow in a perpendicular direction.

The presence of supports, as stated, can have no direct or essential connection with the production of the spiral formations referred to above : yet in all works on botany and physiology the supports are accredited with the production both of the bending spiral movements and the beautiful spiral forms to which they give rise. This, in homely phraseology, is putting the saddle on the wrong horse. I discuss the growth of spiral shells and horns at Plates xiii., xiv., xv., and xvi., pp. 28 to 31 inclusive.

That living spiral structures do not require any external stimulus to cause them to assume the spiral form is abundantly proved by the growth of spiral spermatozoids, ova, bacteria, vorticellæ, jelly-fish, the rays of certain star-fishes, the egg-pouches of sharks and dog-fish ; the majority of shells ; a large proportion of horns, teeth, bones, muscles, nerves ; quite a large number of plants and trees, to say nothing of many climbing plants, and the tendrils of plants and animals forming single and double spirals.

In all these cases no irritability or stimulus is required or present. Professor Sachs, one of the most advanced of physiological botanists, thus expresses himself in favour of the theory of irritability :[1] "It is the tendril plants which are to be looked upon as the most perfect of all climbing plants, having special organs exclusively adapted for climbing. . . . Tendrils are thin, long, filiform organs, which when typically developed *are distinguished by being in a high degree irritable*, especially to continued contact with a solid body.[2] By means of this property tendrils are enabled to twine closely round a thin rod, the stem or haulm of another plant, or the branch of a woody shrub, &c., much as a cord or thin wire may be wound round a pencil, and thus bind themselves fast ; and, since numerous tendrils on any shoot act in the same way, they fasten the latter to foreign bodies, and enable it to climb upwards. *The stem axis is entirely passive* in this process.[3] . . . This coiling up of tendrils fixed to supports is thus, in the same sense as the twining round the support itself, *an effect of irritability.* Those parts of the tendril which are between its base and the point where it is fixed are obviously not able to coil themselves around the support, *although the stimulus which causes the curvature* is propagated to this region ; the effect of the stimulus is simply that the portion of the tendril lying between the fixed point and the rigid base becomes coiled in the form of a corkscrew. In other cases, it is peculiarly-developed parts of leaves, *specially endowed with irritability* and more or less filiform and sensitive to contact, which assume the chief properties of tendrils. . . . In the common fumitory (*Fumaria officinalis*) and the allied *Corydalis claviculata*, the whole of the leaf is branched into fine slender filaments, *and is irritable to contact* and able to twine its separate parts round their bodies. As regards the mechanism of the *irritable curvature induced by contact* (the twining and coiling up of attached tendrils), as well as the coiling up of free tendrils, there can be no doubt that it depends on the process of growth in length and its modification due to transverse pressure on the side which is growing more freely." (The italics in this quotation are mine.)

That the supports do not, as stated by Professor Sachs, act as irritants to plants is plain from this, that *the plants move towards and not away from the supports.* Plants, in short, are, within limits, masters of their own destiny ; they are not the sport of extraneous matter, living or dead. Proof of what is here stated is afforded by the behaviour of other living things, all of which endeavour to escape from *irritation and external stimulation.* Thus, if the tentacles of a medusa or a snail be touched they are instantly withdrawn. If an earthworm or a muscle be stimulated they at once retract or shorten : they endeavour to get away from the irritating substance. The feeble, dying heart invariably contracts on being pricked ; and so of all other sensitive, living things. The tendrils of plants form no exception. If they advance towards, and seize and twine themselves round, a support instead of receding from it, it is not because they are irritable and because the support acts as a stimulus, but because they are expressly formed to lay hold of and utilise supports with a view to strengthening their weak stems, which are too feeble to stand by themselves. The plant has an ulterior object in view when it causes its tendrils to bind it to something stronger than itself. Here there is means to ends. It is not simply a question of irritability and extraneous stimulation, but of adaptation to an obvious purpose. If the tendrils do not withdraw from the support the instant they touch it, it is because their primary function is to seize and make use of it. The theory

[1] "Lectures on the Physiology of Plants," by Julius Von Sachs, translated by H. Marshall Ward, F.L.S., &c.

[2] The effect of irritability on a living plant or animal "to continued contact with a solid body" would be to drive it away from, and not towards, the said body.

[3] It should be here stated that the stem axis is the progenitor of the tendril, and performs its own part in spiral rotation and climbing. No part of a living plant can, strictly speaking, be regarded as passive.

of irritability, so far from explaining the coiling movements of tendrils, makes them utterly incomprehensible. It inconsistently assumes that the tendrils act in a diametrically opposite way to all other sentient, living things. Living things can and do act independently, and as apart from irritability and extraneous stimulation. The compartments of the fœtal heart, for example, open and close with time-regulated beat before they contain blood; the blood being usually but erroneously considered the stimulus which causes the rhythmic movements of the heart. Similarly, the opening and closing movements of the chest in respiration are not caused by the supposed stimulus of the air, as was at one time believed.

The way in which climbing plants behave when they come in contact with supports is highly instructive. They not only advance towards the supports but they throw out additional matter from their bodies in the shape of cells, vascular bundles, woody fibres, &c., to take full advantage of the new connection. In other words, plants not only seize supports but they greatly strengthen by vital processes of growth the bonds of connection. This happens in leaf-stalks, in elongated midribs of leaves, and in tendrils of all kinds. Whenever a hold is taken, the binding link is slowly but surely strengthened. The binding link is increased in volume to make it more powerful and effective. The binding link is doing work, and is added to and strengthened in the same way that the blacksmith's arm becomes more brawny from continued exertion. All this speaks of design, and a Designer manifesting Himself in living things. It also proclaims life an independent, controlling, master force.

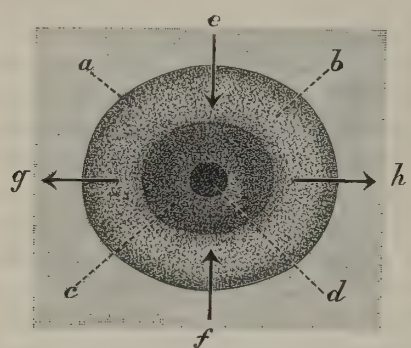


FIG. 222.—Typical cell consisting of a cell wall (a), cell contents (b), a nucleus (c), and a nucleolus (d). The cell can diminish its bulk by centripetal movements, or increase it by centrifugal movements. It can also change shape—its volume remaining the same. In the latter case, the darts e, f indicate the centripetal movement; the darts g, h the corresponding centrifugal movement. The darts also indicate the ingoing nourishing current (e, f), and the outgoing or effete current (g, h). The centripetal and centrifugal movements in the flexor and extensor muscles of the arm are shown at m and n of Fig. 223 (the Author).

I have characterised growth as aggressive and fundamentally a pushing power, and it is so largely in virtue of cell formation, cell development, and cell increase. It is convenient here to speak of cells rather than atoms and molecules. Cells are more readily detected than molecules and atoms; but, strictly speaking, the processes of growth are atomic and molecular in character. Cells are living anatomical entities, and they increase in a great variety of ways; endogenously or from within; exogenously or from without; fissiparously or by division; and gemmiparously or by budding.

Each cell is provided with a cell wall, cell contents (protoplasm of various kinds), and a nucleus with, or without, a nucleolus. There are unicellular plants, and unicellular animals. The cell wall acts as an osmotic medium through which nourishing matter passes into the cell, and effete matter passes out of it. A double current in opposite directions is thus established (Fig. 222, e, f; g, h). It is by means of this double current, in some form or other, that extraneous substances are added to plants and animals, and effete or waste products got rid of. Cells and cell structures have the power of increasing and diminishing their volume, and of changing their shape by centripetal and centrifugal movements. This power of increase and diminution, and of changing shape as apart from either, is at the root of all movement in plants and animals. When a series of cells situated on one surface or aspect of a plant structure increase in size, the cells push and cause the structure to bend on the opposite aspect: when a series of cells situated on another surface diminish in size, the cells pull and cause the structure to bend towards the surface in question. An increase of the cells on the one aspect and a decrease thereof on the opposite aspect make the bending process more effectual and rapid. The increasing and decreasing cells may and do work in unison, and to a given end. They do not oppose each other. The cells are invested with a double power, whereby they can alternately increase and diminish at longer or shorter intervals. Cells which increase at one period diminish at another period, and *vice versâ*. There is therefore a push and a pull in cells and in the structures formed by them.

Similar results are obtained (without change of bulk in the cells) if they act in opposite directions; the one set of cells elongating when the other shortens, and the contrary, as in the sarcous elements of muscles. This is especially true of muscles where the pull is represented by the closing, contracting, or shortening movement; the push by the opening, dilating, or elongating movement. When muscles pass over a joint, those on the one side of the joint shorten when the muscles at the other side elongate, and the converse (Fig. 223). The bending produced in a joint in animals is analogous in all respects to the curvature produced in plants. The two movements, moreover, are produced in exactly the same way, namely, by the increase or diminution, or by the change of shape in opposite directions, of the cells or of the structures formed from and by them.

Plants can bend east, west, north, or south. They can also revolve and twist on their own stems. They are endowed with universality of motion. True, they cannot move from place to place, although some of their spores which are provided with caudate prolongations and cilia can swim freely about The movements of plants are all referable ultimately to changes occurring in the atoms and molecules which form the cells.

The movements in plants and animals are the outcome of life, growth, and development. The form, whether flat, square, round, pentagonal, hexagonal or spiral, indeed whatever its nature, is traceable to the same causes. Movement in every instance precedes form, and movement in particular directions determines form.

Long ago Hofmeister pointed out that the shoots and leaves of all plants when young move after being shaken, and so thoughtful and careful an observer as Mr. Darwin writes: "The most interesting point in the natural history of climbing plants is their diverse power of movement. . . . The most different organs—the stem, flower, peduncle, petiole, midribs of the leaf or leaflets, and apparently aërial roots—all possess this power."

Mr. Darwin, who is an acknowledged authority on climbing plants, divides them into "those which spirally turn round a support, those which ascend by the movement of the foot-stalks, or tips of their leaves, and those which ascend by their tendrils—those tendrils being either modified leaves or flower-peduncles, or perhaps branches. . . . These subdivisions nearly all graduate into each other. There are two other distinct classes of climbing plants, namely those furnished with hooks and those with rootlets."

Mr. Darwin inclines to the opinion "that the transition from spirally climbing plants to root-climbing is not difficult." He founded his belief on the fact that "the young internodes of *Bignonia tweediana* and of *Hoya carnosa* revolve and twine, and likewise emit rootlets which adhere to any fitting surface." [1]

Before dealing finally with the subject of climbing plants and the varied and exquisite spirals formed by them, it may be well to refer very briefly to the plants provided with hooks and rootlets and those which climb by the aid of foot-stalks and the tips of their leaves.

It may be premised that all the parts of plants engaged in climbing are sensitive when young, and that the climbing movements can in no case be regarded as purely accidental. In every instance the climbing is purpose-like; the apparatus for climbing being devised after particular patterns, to secure specific ends.

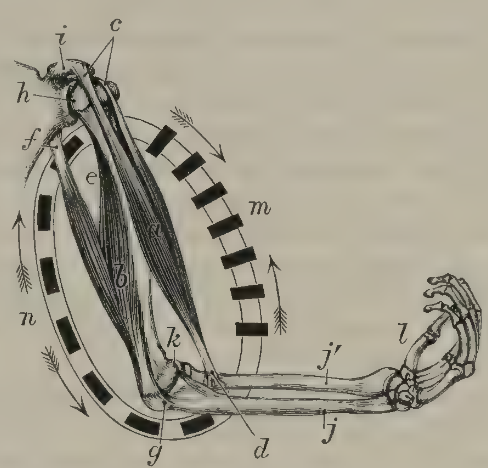


FIG. 223.—Shows flexion or folding of the arm by centripetal movements in the sarcous elements (*m*) of the biceps muscle (*a*), and centrifugal movements in the sarcous elements (*n*) of the triceps muscle (*b*). These movements are reversed in opening out or extending the arm. In this figure the biceps and triceps, and their sarcous elements, form a muscular cycle investing the arm, forearm, and elbow joint; contraction or closing of the cycle on one side of the arm (*m*) being accompanied by dilatation or elongation of the cycle on the other side (*n*) in flexion; the movements, as explained, being reversed in extension. *c*, Origin of the two heads of the biceps; *d*, insertion of the biceps; *e*, *f*, origin of the three heads of the triceps; *g*, insertion of the triceps; *h*, head of the humerus; *i*, coracoid process of the scapula; *j*, *j'*, ulna and radius; *k*, the elbow joint; *l*, the bones of the hand (the Author, 1872).

The hook-climbers are not a numerous class. *Rubus australis*, *Galium Aparine*, *Dipladenia*, *Smilax aspera*, and certain palms furnish examples. Some roses can also ascend trellis work.

The root-climbers are more plentiful. A good example is furnished by *Marcgravia umbellata*. The ivy (*Hedera helix*), *Ficus repens*, and *F. barbata* also fall under this category. The hook-climbers do not revolve, and the root-climbers can scarcely be accredited with movement, not even turning to or from the light.

Vanilla aromatica sends out long roots which depend and creep into crevices and twine round slender supports like tendrils.

Some of the root-climbers—*Ficus repens*, for example—exude a viscid fluid which acts as cement. The rootlets of certain species of *Lycopodium*, according to Mohl, also act as tendrils.

The leaf-climbers are interesting, and present some remarkable modifications of leaf-structures. They climb by the aid of the *sensitive* petiole (leaf-stalk) or by the extended midrib of the leaf. The leaf-climbers occupy an intermediate position between twiners proper and certain tendril-bearing plants.

Clematis glandulosa, *C. montana*, *C. calycina*, *C. microphylla*, *C. Flammula*, *Tropæolum*, *Solanum*, and *Gloriosa superba* furnish examples.

[1] "On the Movements and Habits of Climbing Plants," by Charles Darwin, F.R.S., F.L.S., &c., pp. 2 and 25. (From the *Journal of the Linnæan Society*, 1865.)

In clematis (*C. glandulosa*) the tender, growing, upper internodes revolve against the sun; the average rate of revolution being three hours and forty-eight minutes.

In a plant of this species described by Mr. Darwin [1] the leading shoot immediately twined round a stick placed near it. It made an open spire of a turn and a half in one direction, ascended for a short space straight, and then reversed its spire and wound two turns in an opposite direction. This reversal of the spires made by the clematis to which Mr. Darwin alludes, is not uncommon. It occurs, I find, in the stems of the hop, passion-flower, sweet-pea, convolvulus, cucumber, vegetable marrow, &c. It also occurs in the tendrils of the passion-flower, bryony, cucumber, vegetable marrow, &c.; the reversals in some cases being numerous.

I attach great importance to the reversing spirals formed by the stems and tendrils of plants, as they are obviously the outcome of life and growth as apart from environment, irritability, and extraneous stimulation. This seems abundantly proved by the fact that the reversing spirals occur in stems when not in contact with vertical or other supports, and in tendrils which have not caught hold of anything and are surrounded by air only.

I deal with the subject of reversing spirals further on, and also in the section on "The growth of spiral shells, horns, bones, teeth, feathers, seeds, fruits, plants, &c." of the present work.

In the tropical species of clematis (*C. glandulosa*) under consideration the leaves are broad and ovate and not very well adapted for climbing. The foot-stalks, moreover, are not very sensitive: still, when rubbed for a little, a bending movement towards the side rubbed takes place after a few hours. The under side of the foot-stalk is the more sensitive. The young leaves, slightly hooked, are at first directed upwards, then at right angles to the stem, then downwards. In the latter position the whole petiole and leaf together form a hook which is ready to seize twigs and supporting structures. The leaves, especially the foot-stalks, are afforded an opportunity of attaching themselves to neighbouring supports by the revolving movements which, as has been explained, take place in the growing upper internodes of the plant. The foot-stalks, when they have twisted round and seized a support, soon become much thickened. They are performing work, and become stronger on a principle, well known in physiology, whereby continued action and strain are followed by an increase of substance in the moving parts. Hypertrophy of the heart due to disease of the valves of the heart or other obstruction to the circulation furnishes an example in point.

The petioles or leaf-stalks of *Clematis montana* are far more sensitive than those of *Clematis glandulosa;* a loop of thread weighing only a quarter of a grain causing them to bend. In *Clematis montana* the petioles stand out at right angles to the stem, and where the stem revolves round a vertical support, and they strike it, the revolving movement is temporarily arrested, and the petioles slowly twine round the support, making one or two turns according as the support is thick or thin. Only the petiole which strikes the support behaves in this manner; the opposite petiole is not affected. In these various movements we have an example of a living plant performing a definite function. In Plate cvi., Fig. 1, E, I give an illustration of the petioles of *Clematis montana* twining round dead vegetable stems, taken from nature.

The *Clematis calycina* is a better climber than either of the foregoing. It differs from *Clematis glandulosa* in climbing with and following the sun.

Mr. Darwin gives some interesting physiological and microscopic details in connection with this species (*Clematis calycina*). He says:—

"When the petiole has clasped a twig, it undergoes some remarkable changes, which occur with the other species, but in a less strongly marked manner. The clasped petiole in the course of two or three days swells greatly, and ultimately becomes nearly twice as thick as the opposite leaf-stalk which has clasped nothing. When thin transverse slices of the two are placed under the microscope their difference is conspicuous: the side of the foot-stalk which has been in contact with the support is formed of a layer of colourless cells with their longer axes directed from the centre of the petiole, and very much larger than any cells found in the opposite or unchanged petiole; the central cells, also, are in some degree enlarged, and the whole is much indurated. The exterior surface generally becomes bright red. But a far greater change takes place in the nature of the tissues than that which is externally visible: the petiole of the unclasped leaf is flexible, and can be easily snapped, whereas the clasped foot-stalk acquires an extraordinary toughness and rigidity, so that considerable force is required to pull it into pieces. With this change, great durability is probably acquired; at least this is the case with the clasped petioles of *Clematis vitalba*. The meaning of these changes is plain, namely, that the petioles may firmly and durably support the stem." [2]

The changes referred to by Mr. Darwin as regards increase of substance and strength are all due to growth, and are therefore vital in their nature.

In *Clematis microphylla*, var. *leptophylla*, the long, slender internodes revolve with and against the sun. In this respect this species differs from *Clematis glandulosa*, which revolves against the sun, and *Clematis calycina*, which

[1] Op. cit., p. 26.

[2] Op. cit., pp. 28 and 29.

revolves with it. Its revolutions are also quicker, the average rate for each revolution being one hour and fifty-one minutes. The shoots either twine round or clasp the support with the basal portion of the petiole. The whole leaf (and this is a remarkable circumstance) is, when young, in a continual, spontaneous, slow movement.

In *Clematis Flammula* the shoots, which are thick, straight, and stiff, revolve in the same direction as the sun. It generally makes one revolution in three hours and forty-five minutes.

Mr. Darwin, speaking of this species, states that "the petioles, when so young that they have not separated from each other, are not sensitive; when the lamina of a leaflet has grown to a quarter of an inch in length (that is, about one-sixth of its full size), the sensitiveness is highest; but at this period the petioles are much more fully developed proportionally than the laminæ of the leaves. Full-grown petioles are not in the least sensitive. . . . When a loop of thread weighing only one-sixteenth of a grain was placed on a sub-petiole it very slowly moved through ninety degrees."

Tropæolum tricolorum sends up a thin, flexible stem, which revolves in a course opposed to the sun, its average rate of revolution being one hour and twenty-three minutes. It makes numerous spiral coils round the vertical supports, and when its spiral coiling is arrested by its clasping petioles it sometimes reverses and climbs spirally for a turn or two in an opposite direction. The thin filaments or imperfect leaves, as well as the petioles of the perfect leaves when young, are exceedingly sensitive on all sides. If slightly rubbed they turn to the side assailed in from three to six minutes. The filaments and petioles after a time are inclined to contract spirally.

The stem of *Gloriosa plantii* (*Liliaceæ*) rotates with or against the sun, and sometimes stands still. Its average revolution occupies three hours and forty minutes. The young leaves are nearly vertical; later, by the spontaneous bending of the outer halves of the leaves, they become horizontal. The tip of the leaf forms a narrow, ribbon-shaped projection, which ultimately curves, and becomes a hook strong enough to seize an object and stop the revolving movements of the plant. The leaf is sensitive on its inner side. The petiole is exceedingly sensitive, and responds to the slight continued pressure of a soft thread weighing only the one-sixteenth of a grain. The petiole bends towards the side pressed. The hook, if it catches nothing, remains for a long period open and sensitive; ultimately the tip spontaneously and slowly curls inwards, and makes a button-like, flat, spiral coil at the end of the leaf.

I give a drawing from nature of the spiral coil made by the leaf of *Gloriosa superba* at Plate cvi., Fig. 1, B.

The spontaneous coil made by the tip of the leaf of this plant is a good example of a fundamental, typical, terminal coil.[1]

According to Mohl, *Uvularia* (*Melanthaceæ*) climbs in the same manner as *Gloriosa*. Mr. Darwin, when speaking of *Nepenthes*, says its climbing is effected by the stalk or midrib between the leaf and the pitcher twisting round any support, and remarks that the twisted part *becomes thicker* but that the stalk *often takes a turn when not in contact with any object, and that the twisted part likewise becomes thickened.*

This is an important admission on the part of Mr. Darwin, as it shows that a sensitive part of a plant can coil when not in contact with an object, and that the coil, spontaneously produced, is spontaneously thickened and increased in substance as apart from irritation.

I regard this statement as a confirmation of my view, often expressed, that plants are endowed with independent movements and powers of growth, and that neither irritation nor extraneous substances are required to evoke them.

Mr. Darwin, in his summary on leaf-climbers, makes the following observation: "A petiole excited by an extremely slight weight sometimes bends a little, and then becomes habituated to the stimulus, and either bends no more or becomes straight again, the weight still remaining suspended." He also states that rain, under certain circumstances, is tolerated and does not act as a stimulus. If, however (and this is a subject of great importance in the present connection), plants become habituated to stimuli, and, nevertheless, perform all their functions, the need for stimuli disappears.

Having described briefly certain of the plants which climb by the aid of rootlets, suckers, modified leaves, and hooks, I am now in a position to deal with the climbing plants proper, and the varied and beautiful spirals made by them.

They are illustrated at Plates cvi., cvii., cviii., and cix., pp. 612, 613, 618, and 628.

[1] By a terminal coil I mean a coil which is predetermined or arranged for, and which is, or may be, modified by coming against a support; the primary object of the coil being to twine round something.

PLATE CVI

FIG. 1.

FIG. 2.

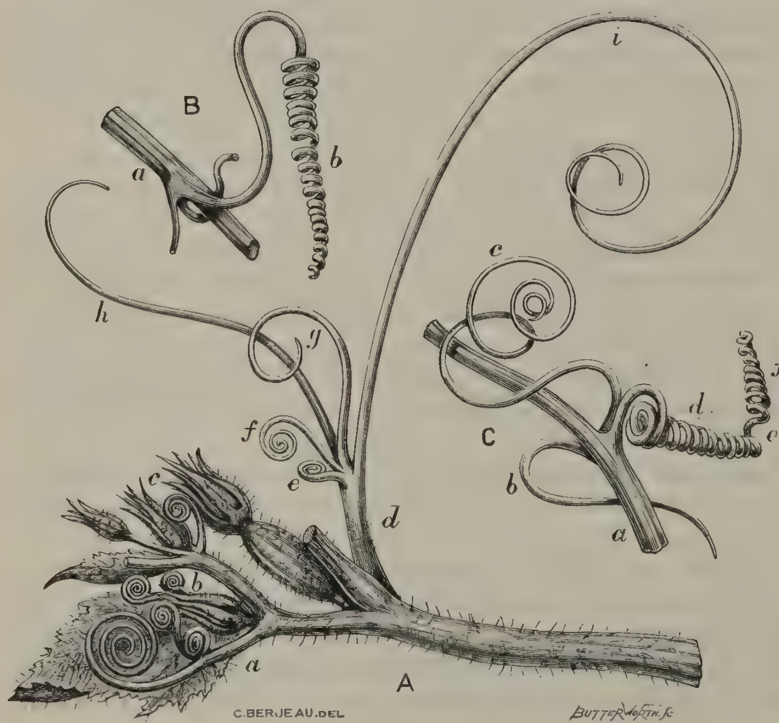


FIG. 3.

FIG. 4.

PLATE CVI

Plate cvi. illustrates spiral formations in climbing plants, tendrils, &c.

FIG. 1.—Shows striking examples of spiral formations in plants.

A. Schubertia (*Physianthus*). Stem of plant making right-handed spiral. B. *Gloriosa superba*. Leaf terminating in spiral whorl. C. Croton (*Codiæum*). Leaf forming right-handed spiral. D. Orchid (*Cypripedium*). Flower forming right-handed spiral.

E. Clematis (*C. montana*). Leaf-stalks forming right and left-handed spirals round alien stems.

F. Convolvulus (*C. arvensis*) forming right-handed spiral round gooseberry twig.

G. Honeysuckle (*Lonicera Caprifolium*), winding from left to right.

H. Two honeysuckle stems entwined and forming left-handed spiral as in the human umbilical cord (Plate xii., Fig. 3), and spiral intestine (Plate xii., Fig. 4). Drawn by C. Berjeau from fresh specimens collected by the Author.

PLATE CVII

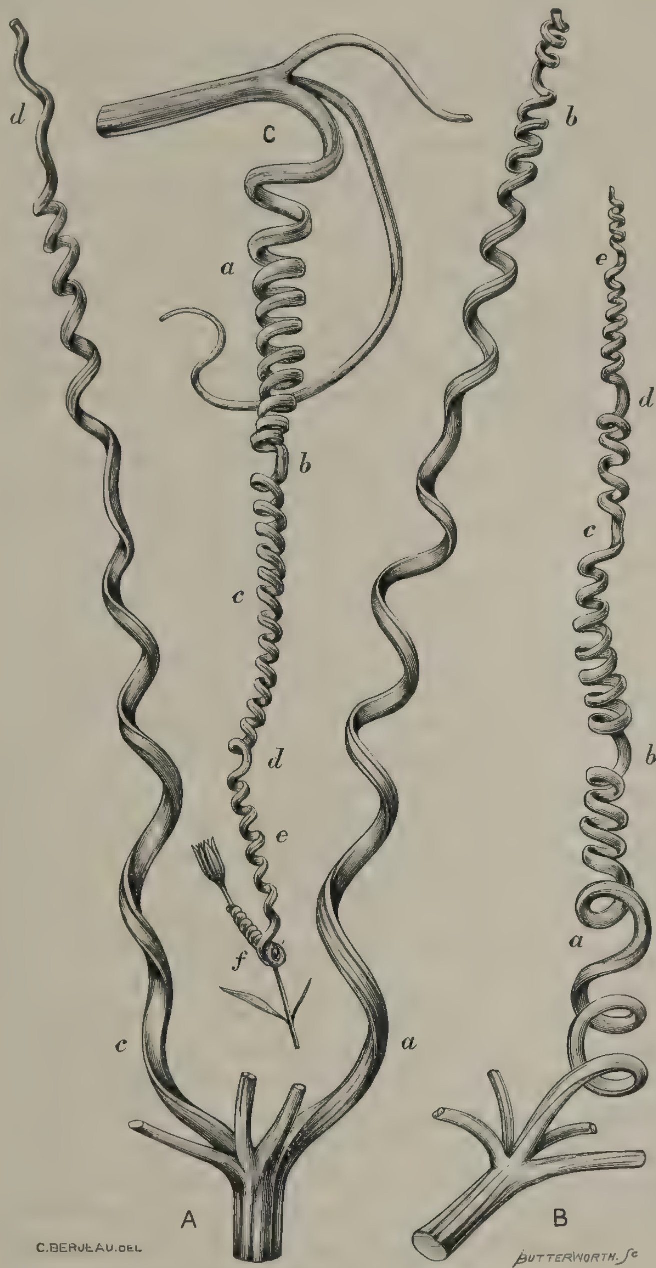


FIG. 2.

FIG. 1.

FIG. 3.

PLATE CVI (*continued*)

FIG. 2.—Horn of the koodoo (*Strepsiceros kudu*) forming an exquisite open left-handed spiral. The imaginary axis (*a*, *b*) has been introduced to show how a foreign substance may be inserted within the spiral coils. Drawn by C. Berjeau from specimen for the Author.

FIG. 3.—Tendrils of vegetable marrow (*Cucurbita Pepo*) forming close and open right and left-handed spires.
A. *a*, *b*, *c*, Tendrils forming close spires; *d*, sub-axis bearing five tendrils; *e*, *f*, tendrils forming right and left-handed spirals; *g*, *h*, tendrils unwinding and straightening and preparing to seize adjacent object; *i*, tendril re-curving in the air, having failed to grasp anything.
B. *a*, Sub-axis; *b*, tendril forming an open right-handed spiral in the air, not having caught anything.
C. *a*, Sub-axis; *b*, tendril straightened and ready to seize anything with which it may come in contact; *c*, tendril re-curving in the air, not having found a support; *d*, similar tendril forming first a right-handed, and then a left-handed (*e*, *f*) spiral, apart from any object touched or seized. Drawn from nature—fresh specimen—by C. Berjeau for the Author.

FIG. 4.—A. Spiral stem of tecoma (*Bignonia*) twisting and forming a right-handed spiral.
B. Sprig of sweet-pea (*Lathyrus odoratus*) with tendrils forming right and left-handed spirals.
C. Stems of asparagus (*Asparagus plumosus*) twisting spirally into each other. The twist is in an opposite direction to that figured at A. They form a left-handed spiral. Drawn by C. Berjeau from fresh specimens collected by the Author.

PLATE CVII

Plate cvii.—This plate illustrates the twining stems in the hop and vegetable marrow: also the reversing spirals made by them; also the single and double reversing spirals made by the white bryony and vegetable marrow.

Fig. 1.—Shows a caught tendril of *Bryonia dioica*, spirally contracted in reversed directions (Darwin).

Fig. 2.—Tendrils of vegetable marrow (*Cucurbita Pepo*), showing fine examples of double or reversing compound spirals. These tendrils, in addition to forming double reversing spirals, are twisted on themselves like the stems of many climbing plants.

A. *a*, *b*, Double reversing spiral formed by twisted tendril; *c*, *d*, a similar double reversing spiral. These spirals are growing freely in the air and touching nothing.

B. Striking example of a double reversing compound spiral tendril growing freely in the air and apart from contact, fixation, and stimulation. The spiral is seen reversing at *a*, *b*, *c*, *d*, and *e*. It consists of alternating right and left-handed spirals, and these are obviously the result of growth and original bias, and are, in this sense, inherent or fundamental.

C. Another example of a double reversing spiral tendril. *a*, Left-handed spiral; *b*, spiral reversing to form a right-handed spiral (*c*); *d*, spiral reversing to form a left-handed spiral (*e*); *f*, spiral reversing to form a right-handed spiral. In this case the tip of the tendril has seized a small flower, but the presence of the flower, as explained, is not necessary to the formation of the double spiral. Drawn from nature—fresh specimen—by C. Berjeau for the Author.

Fig. 3.—A. Spiral bundle of hop stems (*Humulus Lupulus*). The stems twine into each other and form left-handed spirals.

B. Single hop stem forming a left-handed spiral.

C. Another portion of the same stem forming a right-handed spiral. It is not possible that any form of extraneous stimulation could produce right and left-handed spirals in the same stem. This can only be referred to design and original endowment. Drawn from fresh specimens of hops by C. Berjeau for the Author.

§ 196. Stem and Tendril-climbing Plants.

The tendril-climbers are a very numerous class. In 1827, no fewer than 465 species were known to Hugo Von Mohl, but the number has been greatly increased since that period. They are met with in most abundance among the *Dicotyledons*, where the distribution of physiological labour is greatest.

The hop (*Humulus Lupulus*) furnishes an excellent example of a stem-climber. In this useful plant the top of the stem is endowed with an independent power of rotation which enables it to search for a vertical support and to twine round it when found. It happens not unfrequently that three or four hop stems twine into and round each other.

When two or more stems twine together the spirals run from right to left of the spectator, as shown at Plate cvii., Fig. 3, A. They form left-handed spirals.

While the top or growing part of the hop revolves, the stem, as a whole, twists upon itself, and, marvellous to relate, twists in two opposite directions; one part of the stem twists from right to left of the spectator and forms a left-handed spiral (Plate cvii., Fig. 3, B); another part twists from left to right and forms a right-handed spiral (Plate cvii., Fig. 3, C). The tendrils of climbing plants in many cases do the same (p. 24, Plate x., Fig. 1, A, B, C, and Fig. 2, B, C). Even the substance of the tendrils twists (Plate cvii., Fig. 2, A, *a*, *b*, *c*, *d*).

The movement of rotation in the growing top of the hop and the twisting of the stem upon itself in two different directions are inherent vital movements, that is, they are not caused by irritability in the stem, nor by the stem coming in contact with foreign substances. Similar remarks are to be made of all forms of tendrils. The movements referred to take place when the top of the stem and the tendrils are moving freely in space and when the stem and the tendrils are only in contact with atmospheric air.

Mr. Darwin states that "when the shoot of a hop rises from the ground, the two or three first formed internodes are straight and remain stationary; but the next formed, whilst very young, may be seen to bend to one side and to travel slowly round towards all points of the compass, moving like the hands of a watch, with the sun. . . . The revolving movement continues as long as the plant continues to grow; but each separate internode, as it grows old, ceases to move."

Mr. Darwin experimented on seven hop shoots during the months of August and April, and found the average rate of travel in hot weather and during the day to be two hours and eight minutes for each revolution.

Speaking of one of his experiments, he says, "After the twenty-first revolution, the penultimate internode was two and a half inches long, and probably revolved in a period of about three hours. At the twenty-seventh revolution the lower internode was eight and three-eighths, the penultimate three and a half, and ultimate two and a half inches in length; and the inclination of the whole shoot was such, that a circle nineteen inches in diameter was swept by it." In these experiments, it should be noted, *the plants grew unsupported*. The number of internodes engaged in the revolution was usually three. "With all, if in full health, two revolved; so that

by the time one had ceased, that above it was in full action, with a terminal internode just commencing to revolve."

Mr. Darwin experimented with other plants besides the hop. With regard to *Hoya carnosa* he observes, "A depending shoot, thirty-two inches in length without any developed leaves, and consisting of seven internodes (a minute terminal one, an inch in length, being counted), continually, but slowly, swayed from side to side in a semi-circular course, with the extreme internodes making complete revolutions. The swaying movement was certainly due to the movement of the lower internodes, which, however, had not force sufficient to swing the whole shoot round the central supporting stick."

In the case of another asclepiadaceous plant, namely *Ceropegia gardneri*, he allowed the top, which consisted of three long internodes, terminated by two short ones, to grow out almost horizontally to the length of thirty-one inches. "The whole revolved in a course opposed to the sun (the reverse of that of the hop), at rates between five hours fifteen minutes, and six hours forty-five minutes, for each revolution. Hence, as the extreme tip made a circuit of about five feet in diameter and fifteen feet in circumference, the tip travelled at the rate (assuming the circlet to have been completed in six hours) of thirty-two or thirty-three inches per hour." This experiment was made during hot weather, with the plant standing on Mr. Darwin's study table, and he enthusiastically remarks, "It was an interesting spectacle to watch the long shoot sweeping, night and day, this grand circle in search of some object round which to twine."

It may be observed that the axes or stems of nearly all twining plants are themselves twisted; the direction of the twist coinciding with the direction of the spontaneous revolving movements.

The degree of twist, according to Mr. Darwin, is modified by the smooth or rough nature of the supports round which climbing plants twine. I am disposed to accept this statement with reservation, believing as I do, that the twisting of the stems of climbing plants, equally with the spontaneous revolutions made by their tops, are independent vital movements, and are not due to irritability or stimulation caused by coming in contact with supporting structures. This follows, because the revolutions and twistings go on when climbing plants are not provided with supports, and when they grow freely in space.

A question here arises as to whether the revolutions occurring at the growing tops of climbing plants cause the twisting of the stems or the converse. This question is not easily answered. Hugo Von Mohl was of opinion that the twisting of the axis caused the revolving movement. Palm and Leon, however, pointed out (what was also known to Von Mohl himself) that in certain climbing plants, the hop for example, some internodes twine from right to left, while others twine from left to right. It happens occasionally that the reversals in stems and tendrils, as already stated, are numerous. The twisting of stems in one or more directions is, according to Mr. Darwin, a mechanical device for giving greater rigidity and strength; the stems of climbing plants being, as a rule, relatively weak.

It may very well be that the twisted stem is stronger than one which is not twisted, and that the twisting, as explained by Hugo Von Mohl, is the cause of the rotation. The fact that the internodes in certain plants twist in opposite directions does not destroy the "greater rigidity" theory of Mr. Darwin, and it only partially invalidates the "twisting stem" theory of Von Mohl, as the rotation can occur throughout the whole stem instead of merely at the top of the stem. If the rotation was always in the same direction as the twist in the highest internodes then Von Mohl's theory would be established, but it happens that in climbing plants with internodes twisting in opposite directions, the rotation is invariably in only one direction. The rotation is likewise only in one direction in climbing plants with internodes all twisting the same way. In this case the directions of the rotation and the twist correspond. It is difficult to understand rotation as apart from twisting in the stem, and the fact that, in the majority of climbing plants with twisted stems, the rotation is in the same direction as the twist, goes far to prove the point.[1]

The opposite twisting in the internodes of the stems of certain plants, it appears to me, makes for symmetry as well as strength. The twisting in one or more directions, and the spiral movements in the stems of plants, are plainly traceable to growth and inherent vital power, and are in no sense dependent upon irritability and extraneous stimulation.

Mr. Darwin, while admitting "that there must be some connection between the capacity for climbing and axile twisting," is of opinion that rotation in the growing extremity of the stem is not caused by the twisting of the stem. Thus in the hop the revolving of the stem, according to him, apparently commenced before the twisting of the stem occurred; and in a hop which had made thirty-seven revolutions the stem had only twisted three times upon

[1] In *Hibbertia dentata* the revolving movement of the top shoot is sometimes in one direction and sometimes in another, but the twisting of the stem is invariably from left to right. This rather goes to prove that the revolving has nothing to do with the twisting, and even occurs in spite of it. It probably is the exception to prove the rule.

itself. In a young *Siphomeris* or *Lecontea* which had revolved for several days, the internode had only twisted on its axis once.[1] Further, in many leaf-climbing and tendril-bearing plants the internodes are not regularly twisted, but the plants regularly perform revolving movements like those of twining plants.

The power of revolving largely depends on the health and vigour of the plant, and the rotatory function inheres in each separate internode, so "that the cutting off of an upper internode does not affect the revolutions of a lower one. When, however, Dutrochet cut off two whole shoots of the hop, and placed them in water, the movement was greatly retarded; for one revolved in twenty hours and the other in twenty-three hours, whereas they ought to have revolved in between two and two and a half hours."

Mr. Darwin states that "A decrease in temperature always causes a considerable retardation in the rate of revolution. . . . When twining plants are placed near a window in a room, the light in some cases has a remarkable power on the revolving movement, but different in degree with different plants: thus *Ipomœa jucanda* revolved in five hours twenty minutes, the semicircle from the light taking four hours thirty minutes, and that towards the light only one hour; *Lonicera brachypoda* revolved, in a reversed direction to the *Ipomœa*, in eight hours, the semicircle from the light taking five hours twenty-three minutes, and that to the light only two hours thirty-seven minutes.

"From the rate of revolution in all the plants which I have observed being nearly the same during the night and the day, I infer that the action of the light is confined to retarding one semicircle and accelerating the other, so as not to greatly modify the whole rate. This action is remarkable when we reflect how little the leaves are developed on the young and very thin revolving internodes. It is the more remarkable as botanists have thought that twining plants are but little sensitive to the action of light. . . . With most twining plants all the branches, however many there may be, go on revolving together; but according to Mohl the main stem of *Tamus elephantipes* does not twine —only the branches. On the other hand, with the asparagus, the leading shoot alone, and not the branches, revolved and twined; but it should be stated the plant was not growing vigorously."

Plants in many cases cease to revolve for a time when disturbed and carried from one place to another. This shows a delicate sensibility in plants which is rarely if ever taken into account: it proves that plants are living entities, not impassive, automatic machines.

Hugo Von Mohl and Mr. Darwin were disposed to attribute the twisting of the stems of climbing plants to the nature of their supports. Thus Von Mohl asserted that when a stem twines round a smooth cylindrical stick it does not become twisted. Mr. Darwin, following Von Mohl, had "allowed kidney beans to run up stretched string, and up smooth rods of iron and glass, one-third of an inch in diameter, and they became twisted only in that degree which follows as a mechanical necessity from the spiral winding.[2] The stems, on the other hand, which had ascended the ordinary rough sticks were all more or less and generally much twisted."

That the smooth and rough rods do not actually cause the twisting of the stem is admitted by Mr. Darwin in a subsequent passage, for he states that "As soon as the stems which had ascended the iron rods reached the summit and became free, they also became twisted: and this apparently occurred more quickly during windy weather." Here it will be observed we have twisting of the stem occurring quite independently either of the smooth or rough supports, and apart from irritation and stimulation of every kind. Moreover, and as is well known, many plants which are not twiners, and never have had supports, twist upon and round their own axis, as witness the twisted bole of the plane tree (Plate xlii., Fig. 1, p. 68) and that of the great Spanish chestnut given at Fig. 2, Plate cxiv.

As regards the movements of rotation occurring in the free or growing extremities of climbing plants and the twisting movements occurring in the stems thereof, I am disposed to take up a position between Von Mohl and Mr. Darwin. I feel that a living, spiral climbing plant with a twisted stem will almost inevitably cause its free and growing extremity or shoot to rotate: the life, as it were, screwing it into space. On the other hand, a free-growing climbing plant whose growing extremity is endowed by nature with the power of rotation will in time, and of necessity, induce a spiral twist or torsion in the stem. This seems to me a mechanical necessity. The revolving and twisting movements are, in a sense, complementary; the movements are, moreover, with very few exceptions, always in the same direction. The rotatory movement (if it be first in the order of time) naturally produces torsion. If, on the other hand, torsion takes the lead, rotation follows. The movements are determined to a large extent by the circumstances in which the different parts of the stem are placed as regards freedom and comparative fixity, and also as regards the degree of flexibility and elasticity. On the whole, perhaps, the preponderance of evidence favours Von Mohl's view, namely, that the twisting of the stem precedes the rotatory movement in the extremity of the stem. One thing, however, is quite clear: the number of twists in the stem does not correspond with the number of rotations made by the free extremity during a given period.

[1] It, of course, does not follow that for every revolution made by the top of the stem there should be a corresponding twist in the stem. The effect of such an arrangement would be to twist up and wrench off the upper from the lower part of the plant. Excess of twining in the stem would also interfere with the ascent of sap and the circulation of sap generally.

[2] Mr. Darwin here admits that the twisting of the stem is necessitated by the spiral winding of the stem.

The twisting of the stems of climbing and other plants and trees is clearly referable to the life, and not to irritability and the presence of extraneous supports supposed to provide a stimulus and occasion growth in particular directions. All the authors, Von Mohl excepted, who have investigated the subject declare that the spiral twining of plants is due to a natural tendency to grow spirally. Von Mohl, however, maintains "that twining stems *have a dull kind of irritability, so that they bend towards any object which they touch*." Von Mohl's theory is untenable because, as already stated, stems twist when they are growing freely in space and touching nothing.

Mr. Darwin, who opposed Von Mohl's view after experiments, writes as under : "Hence I conclude that twining stems are not irritable ; and indeed it is not probable that they should be so, as nature always economises her means, and irritability would be superfluous." If twining stems, however, are not irritable, it follows as a corollary, that irritability is not the cause of the twining, and this is my contention.

Mr. Darwin instituted experiments to show that the upper part of a growing sapling could be made by the aid of the hand to describe a circle resembling that performed by the tip of a spontaneously revolving plant without the sapling having its stem twisted. To prove this he marked one side of the sapling ; the marked surface, he informs us, being successively directed upwards, then laterally, then downwards, then upwards again.

I have repeated this experiment and made others in the same direction, and am fully convinced that a certain amount of temporary torsion is invariably produced. The fact that the marked portion of the stem in Mr. Darwin's experiments faces alternately upwards, laterally, downwards, laterally, and upwards again makes this clear. It is a question of elasticity and yielding at every point. If a rigid bar of iron be fixed in a vice at one end, the hand has no power to make it either revolve or twist at the free end. If, however, an elastic spar of wood be fixed in the same way the hand can cause it to revolve and twist to a slight extent at the free end. In the case of the sapling, similarly treated, the degree of twist and the amount of revolution are, because of the greater elasticity, considerably increased.

I selected for my experiments a growing ash sapling, three and a half feet in height, and this I stripped of its branches and leaves, the top tuft excepted. I also peeled off a straight portion of bark about one-eighth of an inch in breadth ; the strip running as a white line from the root to the top of the sapling.

My experiments are fully illustrated at Plate cviii., p. 618.

First Experiment.—I seized the top of the ash sapling *loosely* between the fingers and thumb of the right hand and made the top describe a circle with a diameter of two feet or so. I could feel there was a tendency to a twisting of the stem, but I could detect no spirality in the white line formed by the removed bark.

Second Experiment.—I seized the top of the ash sapling a little lower down and *firmly* to prevent the top twisting within the fingers and thumb of the right hand. I then repeated the movement of rotation. I now saw a slight degree of spirality in the white line caused by the removal of the bark. I also experienced a distinct feeling of torsion in the right hand.

Third Experiment.—I seized the ash sapling still lower down and *firmly* with the right hand. On repeating the movement of rotation the white line occasioned by the peeling of the bark assumed a distinctly spiral aspect amounting to quite a half turn. The degree of torsion felt by the right hand was unmistakable, and much greater than I anticipated it would be. These experiments can be readily repeated. I am inclined to think Mr. Darwin was misled by holding the top of the sapling too loosely, and by the stem of the sapling yielding in every direction while the experiment was in progress. My results are figured at Plate cviii., Fig. 1, A.

That the twisting was disguised by the mobility, flexibility, and elasticity of the sapling is proved by the following additional experiments.

I took a rigid bar of iron and fixed the lower end of it firmly in a vice ; the bar being placed in a vertical position. I found I could not make the upper or free end of the bar describe a circle or movement of rotation.

I then fixed the lower end of an elastic cane in the vice, and found that on seizing the upper or free extremity firmly with the right hand I could produce a considerable degree of rotation and a slight degree of twisting.

When I treated the green sapling in the same way the amount of rotation and twisting was greatly increased.

I performed yet another experiment. I fixed firmly in a vice, by their lower ends, in a vertical position, two pieces of rattan cane, each measuring two and a half feet in length and a quarter of an inch in diameter. I then bound the upper portions of the two rattans to each other by means of a hand vice. When I seized the hand vice and made the tops of the rattans perform a movement of rotation, the two rattans not only twisted individually, but they developed a double or right and left-handed spiral with an untwisted portion between analogous in every respect to that witnessed in the stems and tendrils of many twining, climbing plants (Plate cviii., Fig. C). A similar result was obtained when I took a piece of matting or bass and fixed it at both ends in a vertical position and applied torsion to its central part by means of the fingers and thumb (Plate cviii., B, p. 618).

PLATE CVIII

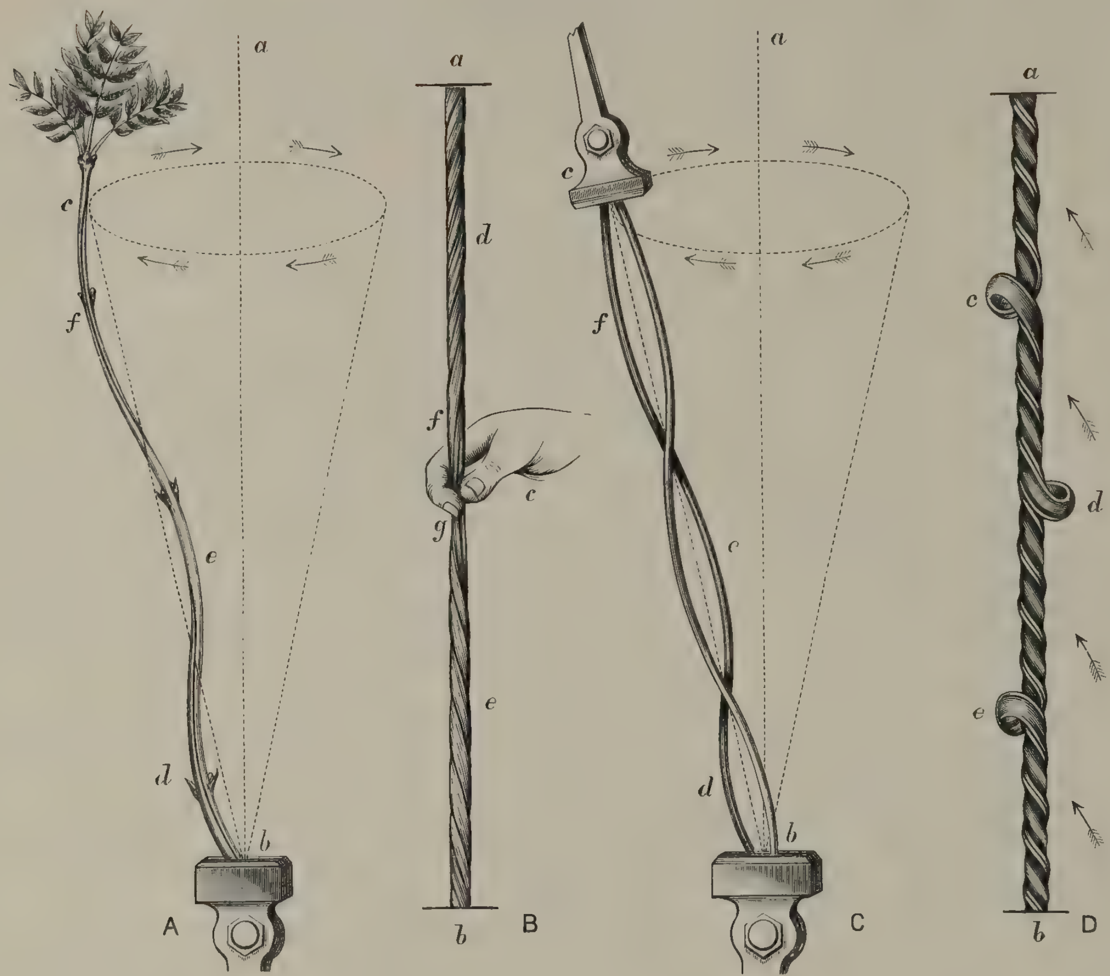


PLATE CVIII

Plate cviii. illustrates experiments showing how torsion is produced in the stems of twining plants whose summits revolve; how double complemental curves are developed in climbing plants, and how in many cases double and opposite spirals are generated in the stems and tendrils of twining plants.

A. Green sapling of ash 2 feet 6 inches long, the lower end of which is fixed in a vice. When the top of the sapling is firmly grasped by the right hand at the point *c*, and made to revolve and describe a circle in the direction indicated by the arrows, the sapling is thrown into complemental and opposite curves as seen at *d*, *e*, *f*. The axis of rotation is given at *a*, *b* of figure. Not only is the sapling thrown into double opposite curves, but the stem of the sapling is twisted at top and bottom in two opposite directions, as shown at *d* and *f*; the portion of the stem at *e* being very little twisted, and remaining, so to speak, neutral. Compare with *f*, *g* of B (the Author).

B. Portion of vegetable fibre (bass matting) fixed at *a* and *b* and twirled between the finger and thumb of right hand (*c*). The part of the fibre at *f*, *g* remains untwisted; whereas the parts *d* and *e* are converted into right and left-handed spirals respectively, as in many stems of twining plants and tendrils (the Author).

C. Two thin parallel rattan canes two and a half feet long fixed in two vices *b* and *c*; the vice *b* being attached to a bench. When the top vice (*c*) is seized firmly by the right hand and made to describe a circle as indicated by the arrows, the rattans separate and develop opposite and complemental curves—the curves of the one (*d*, *e*, *f*) exactly corresponding to similar curves made by the sapling at *d*, *e*, *f* of Fig. A. At *d* in Figs. A and C the spiral is left-handed, whereas between *e* and *f* it is right-handed. The spirals reverse at *e* as at *f*, *g* of Fig. B. The description given of the rattan cane marked *d*, *e*, *f* applies to the other rattan cane which is not lettered. The rattan canes during the revolving process are slightly twisted on themselves at top and bottom (*d* and *f*), the portion *e* remaining untwisted or neutral. The axis of rotation is given at *a*, *b* (the Author).

D. Flat band of india-rubber fixed at *a*, and twisted at the end *b*, so as to form a left-handed spiral as indicated by the arrows. When the twisted process is continued beyond a certain point, the band kinks or loops as shown at *c*, *d*, *e*; these kinks or loops being directed to left and right alternately, the spiral reversing its direction at the kinks. The curious phenomenon is presented of a continuous left-handed spiral with a series of reversals in it which suggest reversals in the stems and tendrils of plants. Compare with Fig. B, where right and left-handed spirals are produced by fixing a vegetable fibre at both ends and applying torsion at the centre of the fibre (the Author).

I performed the following final experiment. I took a flat band of india-rubber, and, fixing one end of it, applied torsion to the unfixed end. When the torsion was carried to a certain point, the band began to kink, loop, or double upon itself. Continuing the torsion, I observed that the kinks were directed alternately from right to left and from left to right (Plate cviii., Fig. D).

The reversing of the kinks did not produce right and left-handed spirals of the twisted band as a whole: only the spirals forming the kinks were reversed.

This experiment differed from that of the bass fibre fixed at both ends; the torsion being applied between the fixed points. In this case, the lower portion of the bass fibre was converted into a left-handed spiral; the upper portion into a right-handed spiral (Plate cviii., Fig. B).

From these experiments I am inclined to infer that the spontaneous revolutions performed by the stems and tendrils of climbing plants inaugurate and determine the nature and degree of twisting witnessed in both. There is obviously a connection between the rotatory and twisting movements, and, curiously enough, the single and double twisting referred to, while apparently a consequence of, does not interfere with, or destroy, the movement of rotation. Of course, the opposite view may be adopted and be equally satisfactory; the single and double twists and spirals in the stems and tendrils producing the movements of rotation. Whichever view be taken, it is quite obvious that the life and growth of the stems and tendrils must be accredited with the rotatory and twisting movements. They cannot be referred either to irritability, stimulation, or contact with foreign substances. The life which actuates the growing stems and tendrils takes the place of the living hand in producing the several movements witnessed in the experiments. Of this there cannot, to my mind, be a shadow of doubt. This interesting subject is further discussed in another part of the work.

The principle here involved is one of great importance. One of two things is evident: either the life and the directive agency which the life exercises are the cause of the rotation and twisting of the stems and tendrils, or both movements are produced mechanically by the so-called irritability of the plant tissues, by artificial stimulation, and by coming in contact with foreign substances.

If the first view be adopted, then the life inaugurates, continues, and perpetuates all the movements witnessed in plants; and the plants work out, within limits, their own destinies. If the second view be adopted, then plants are the offspring of circumstance, and their movements are inaugurated, continued, and controlled by extraneous substances, which form no part of themselves. Irritability of constitution, artificial stimulation, and contact with foreign matter become a necessity. The questions of environment and ultimate destiny here crop up, and have to be considered together. If environment leads or predetermines, then the plant is the slave and not the master of the situation. All its parts are moulded or fashioned, and all its functions regulated, by extraneous, inert, insentient matter. According to the mechanical theory dead matter is supposed to dictate the conditions of life and development. Design in living plants and animals largely or wholly disappears. The elements of the inorganic kingdom dominate, control, and even form the several parts of plants and animals. In the vegetable kingdom, according to this theory, the sensitive plant is not allowed to take advantage of its sensitiveness; the insectivorous plant is denied the power of seizing, destroying, and digesting a great variety of insects; the climbing plant is not allowed to raise itself from the ground by ever so little without the aid of a support; the sensitive tendrils of plants, although expressly formed for grasping purposes, are not permitted to seize anything unless stimulated and set in motion by the dead or living matter they touch. In the animal kingdom, according to the theory of irritability, the eye is formed by the light and not by the living creature with the object of viewing the light and what the light reveals; the ear is formed by sound, and not by the animal as an organ to receive and appreciate sound waves produced by the vibration of sounding bodies in space; the sense of smell is produced by extraneous odoriferous substances floating about in the atmosphere, and not by the animal as an organ expressly constructed to sniff up and realise the presence of the smelling bodies; the sense of taste is produced by external sapid substances coming in contact with particular parts of the body (tongue, palate, and fauces), those parts not being expressly formed and differentiated by the animal for the purpose; the sensitiveness of the skin or common covering of the body is produced by the atmosphere and whatever touches it, and not by the creature whose protection and safeguard it is.

All this, in my opinion, is wrong. Such a doctrine is degrading not only to the plant, but also to the animal, and especially to man, the highest representative of the animal kingdom. The facts, moreover, are wholly opposed to such a view. Even cursory observation and the simplest experiments go to prove that plants and animals are superior to their surroundings and environment. Living plants and animals use, and, if I may be allowed the expression, abuse the dead matter supplied by the elements; they select, appropriate, and assimilate only such matter as suits their purpose at a particular period, and they reject all other matter. They are, in every instance, and under all circumstances, the masters of the situation. The life, and the directive force or agency always associated

with the life, produce elaboration or differentiation of parts, and the sense or other organs fitted to deal with all external conditions. If the plant or animal be not equal to this it ceases to exist. It is not a question of unlimited modification through untold ages by externalities. It is a question of life as a fundamental factor ; life as a directive agency ; life as a power, for the time being, and while it lasts, superior to all other powers ; life as a reality with a great First Cause or Divine Author behind it.

The vital processes of the plant and animal are regulated by fixed laws in the same way that the movements and changes in the elements are, but (and here comes the essential difference) the organic kingdom is superior to, and has the pull over, the inorganic kingdom.

Of course, it is not denied that the external conditions to which plants and animals are exposed cause them to modify to a slight extent their forms, functions, and habits : but in these modifications it is the life (and the First Cause behind it) which inaugurates and produces the modifications, and not the converse. Moreover, the modifications are always exceedingly limited, and do not in any case destroy the identity of the plant or the animal. The plant and animal are distinct entities in nature. They are not at the beck and call of the elements, which are, in a sense, their slaves.

I am here treading on difficult and dangerous ground, but I cannot accept the view that plants and animals, up to man himself, are mere automata, and the product of endless modifications due to external and internal conditions and surroundings. Least of all, can I believe that living things are the product of *brut* matter and spontaneous generation. On the contrary, a wide survey of the situation forces me to conclude that living things (plants and animals) are the result of distinct creative acts ; the work of a Creator Who not only forms the plants and animals and provides for their continuance, but Who fixes the limits within which plants and animals may vary. Certain I am, that plants and animals are not the sport of the elements. Their incomings and outgoings in time and space are all the result of arrangement and design. The only question which remains—and it does not greatly, if at all, affect the powers and prerogatives of life—is this : Has there been one, or several creations ? Has there been a single creation for plants as a whole, and a single creation for animals as a whole ? Has there been a primordial, all-sufficient protoplasm for plants, and another for animals, or was there originally only one life-stuff for both—evolution producing all the rest ? No such single life-stuff has been discovered, and as protoplasm varies infinitely, and each germ, seed, and egg only produces and perpetuates its like, the weight of evidence is in favour of separate creations, at least for the leading classes of plants and animals (types).

Separate creations, and limits or bounds outside of which plants and animals may not stray, accord with the order and design everywhere perceptible in the vegetable and animal kingdoms at the present day. Crosses between nearly allied forms are only possible within very narrow limits. Barrenness is a characteristic of hybrids in the animal kingdom, and, within limits, also in the vegetable kingdom.

It cannot be doubted that law and order regulate all departments of the organic kingdom as they do the inorganic kingdom. Evolution does not exclude the operation of law, neither is it incompatible with the existence of a great First Cause ; a Designer Who provides everything which lives and moves with its appropriate form, function, and environment. To build up a complicated, compound being like man, from an apparently homogeneous jelly-looking speck through innumerable animal forms coming down the ages, requires an infinitely greater degree of prescience and power than would be required for his separate creation. This consideration supports the belief in the separate creations of the leading classes or types of plants and animals up to man ; man being his own archetype.

The argument for design is not seriously affected, far less destroyed, by the modern view of the ancient doctrine of evolution, for as the Rev. A. D. Sloan well puts it, " You can only evolve what has been involved or woven in ; you can only unfold what has first been infolded ; you can only work out what has first been wrought in ; you can only develop what already exists ; you can only bring to light possibilities which are already latent. You cannot get more out of the seed than the reproduction of the parent plant ; you can get the oak from the acorn, nothing more ; you can get the chick from the egg, nothing more. To claim more would be to claim effects without causes, which is unthinkable. Life presupposes life, intelligence an intelligent Designer and Creator."

Mr. Darwin states that there is a most important difference between the artificial rotation of the tip of the sapling and the spontaneous rotation of the tip of a twining plant. According to him, " The upper part of the sapling moves as a rigid body (this, according to my experiments, is a mistake) and remains straight ; but with twining plants every inch of the revolving shoot has its own separate and independent movement." He adds : " If we look to the one, two, or several internodes of a revolving shoot, they will all seem to be more or less bowed either during the whole or during a large part of each revolution. Now if a coloured streak be painted (this was done with a large number of twining plants) along, we will say, the convex line of surface, this coloured streak will after a time (depending on the rate of revolution) be found to lie along one side of the bow, then along the concave side, then on the opposite side, and, lastly, again on the original convex surface. This clearly proves that the internodes,

during the revolving movement, became bowed in every direction. The movement is, in fact, a continuous self-bowing of the whole shoot, successively directed to all points of the compass." He then proceeds to explain the phenomenon as follows: "Now, instead of bending the sapling, let us suppose that the cells on its whole southern surface were to contract from the base to the tip, the whole shoot would be bowed to the south; and let the longitudinal contracting surface slowly creep round the shoot, deserting by slow degrees the southern side and encroaching on the eastern side, and so round by the north, by the west, again to the south; in this case the shoot would remain always bowed, with the painted line appearing on the convex, on the lateral and concave surfaces, and with the point of the shoot successively directed to all the points of the compass. In fact we would then have the exact kind of movement seen in the revolving shoots of twisting plants. I have spoken in the illustration, for brevity's sake, of the cells along each face successively contracting; of course turgescence of the cells on the opposite face, or both forces combined, would do equally well."

From the foregoing it will be evident that Mr. Darwin refers the twining movements in the stems of climbing plants to the turgescence or contraction of the cells on one side of the stem or to a combination of both; that is, to turgescence on the one side and to contraction on the opposite side. His description is by no means clear, for he says, "Let us suppose that the cells *on the whole southern surface* of the sapling were to contract from the base to the apex, the whole shoot would be bowed to the south." This is intelligible, but he adds, "Let the longitudinal contracting surface *slowly creep round the shoot, deserting by slow degrees the southern side and encroaching on the eastern side, and so round by the north, by the west, again to the south.*" Here a spiral movement of the cells, *not confined to one surface*, is assumed, which is at variance with the first part of the statement, where the cells *on the whole southern surface* are supposed to contract.

Cells contracting on one surface or side of a shoot will, doubtless, cause the shoot to bend, but in order to make the shoot *twist and twine* there must be a spiral movement of all the cells and tissues forming the shoot.

A fundamental question is involved in Mr. Darwin's explanation which requires to be settled. It is this What causes the turgescence or the contraction of the cells, or the combination of the two?

Plainly, the turgescence and the contraction to which Mr. Darwin alludes are not accidental. The life and growth of the climbing plant, plus Design, can alone explain the phenomena.

The result desiderated can only be achieved by the atoms and molecules which form the cells acting in definite spiral directions according to fixed laws. The turgescence and contraction of the cells in different regions (indeed all over the stem) are regulated by the vital force of the climbing plant. The atoms, molecules, cells, and tissues of the stem are all under control, and all are impressed with the spiral tendency from the first. Moreover, and as has been already explained, the cells under the influence of the life can be made to increase or diminish alternately in any part of the stem; the cells, which are full of sap and turgescent at one time, containing less sap and being smaller at another time. The cells are endowed with a double power, whereby they can alternately expand and contract, or they can change their form without changing their volume, in a manner analogous to that by which the sarcous elements of muscles and the hollow viscera of vertebrates change shape. All the movements in living tissues, plant and animal, are referable to changes occurring in the atoms, molecules, and cells forming the tissues. There is a distinct analogy as between the movements of the various parts of plants and animals, and this is every day becoming more apparent.

Other examples of twining stems, and of stems twisting into each other, are to be seen in the tecoma (*Bignonia*) and asparagus (*A. plumosus*). I give original illustrations of these at Plate cvi., Fig. 4, A and C, p. 612.

The tecoma stems twine round each other from left to right of the spectator; the asparagus stems, on the contrary, twine from right to left of the spectator.

Numerous other examples of twining stems, leaves, flowers, &c., might be adduced.

Thus schubertia (*Physianthus*) and *Convolvulus arvensis* make beautiful symmetrical spirals round vertical supports, natural or artificial. The stem of the convolvulus, while it twines round a support, also twists upon itself. Both plants twine from left to right of the spectator. The honeysuckle, on the other hand, twines from right to left of the spectator. I give original illustrations of these three plants at Plate cvi., Fig. 1, A, F, and H, p. 612.

The clematis (*C. montana*) causes its leaf-stalk or petiole to coil round everything—its own stem included. The petiole is sensitive, and forms in many cases a peculiar tight, cloth-hitch knot. I give an original figure at Plate cvi., Fig. 1, E, p. 612.

The croton (*Codiæum*) displays a twisted leaf; the spiral running from left to right of the spectator as shown at Plate cvi., Fig. 1, C, p. 612.

The flower of the orchid (*Cypripedium*) presents a peculiar twisted, waved arrangement not unlike the leaf of the croton (Plate cvi., Fig. 1, D).

The free extremity of the leaf in *Gloriosa superba* terminates in a beautiful left-handed spiral whorl with a close coil (Plate cvi., Fig. 1, B).

One of the best examples of a twisted revolving stem lavishly supplied with spiral revolving tendrils is furnished by the passion-flower (*Passiflora quadrangularis*), original drawings of which are given at Plate x., Fig. 1, A, B, C, p. 24. This plant, as its name indicates, is, in parts, exceedingly sensitive and responsive. Its stem and tendrils may, and often do, twist in opposite directions, and so form right and left-handed spirals. The double reversing stems and tendrils can only be regarded as natural products. This follows because they are frequently met with growing freely in the air and when not in contact with supports or foreign matter of any kind. The tendrils, which are the most sensitive parts of the passion-flower, appear as long, slender filaments nearly straight at first. They very soon begin to bend and coil and develop a single or a double reversing spiral, either with or without supports.

In other plants—the white bryony (*Bryonia dioica*), for example—the tendrils are closely coiled up to begin with, and gradually unfold and straighten before seizing a support. Ultimately they form single and double reversing spirals as in the passion-flower (Plate cix., Fig. 3, *u*, *v*, *w*, p. 628).

The same is true of the vegetable marrow (*Cucurbita Pepo*), Plate cvi., Fig. 3, B, C; Plate cvii., Fig. 2, A, B.

The single and double reversing spirals referred to are also met with in the bean, sweet-pea, gourd, cucumber, and other plants.

Mr. Darwin and Professor Sachs have given it as their opinion that the single and double reversing spirals met with in tendrils are not natural products, but are formed artificially and mechanically by the irritability of the tendrils, and by their coming in contact with natural or artificial supports at some periods of their lives. They refer the spirals to irritability, extraneous stimulation, fixation, and torsion. I combat the mechanical view of these productions in the section headed "The growth of spiral shells, horns, bones, teeth, feathers, seeds, fruits, plants, &c." (p. 672).

I oppose the mechanical view for the following reasons :—

1. My observations and experiments are against it.

2. Other spiral structures in nature are not produced by irritation and contact with foreign bodies. They grow spirally.

3. Some tendrils are spiral to begin with, and open out, straighten, and recoil before they seize anything.

4. The tendrils, which are straight to begin with, curve and coil and form single right or left-handed spirals with the coils all running in one direction. The single spirals are grown in the air, and are completed with or without coming into contact with a foreign substance.

5. The straight tendrils in some cases form compound or double reversing spirals with the coils running in opposite directions. In these instances there may be one or many reversals. The double reversing spirals, like the single ones, are grown and completed in the air with or without coming into contact with supports.

6. Supports and fixation of the free ends of the tendrils are not necessary to the production of either the single or the compound double reversing spirals.

7. The fact that a tendril may reverse its spirals six, eight, or more times shows that it is not simply a question of mechanical counter-torsion to prevent rupture of the tendril. If this were all, a single reversal would be as good as two or more.

8. The stems of plants, as well as the tendrils of plants, make single and double reversing spirals. This they do when growing freely in the air, and when they are not in contact with supports or fixed to anything.

9. If the stems of plants form double reversing spirals, as apart from supports and contact with foreign substances, there is no reason why their tendrils should not also form reversing spirals under similar circumstances.

10. There is no proof that stems and tendrils are irritable, and that irritability is necessary to the production of vegetable spiral formations. The stems and tendrils are sensitive, but this is all that can be said. Shells, horns, bones, teeth, feathers, seeds, cells, vessels, &c., grow spirally as apart from irritability.

11. The coils in compound double reversing spirals are said to balance each other, the right-handed coils in every instance equalling in number the left-handed coils. This is not the case: the number of right and left-handed coils, not unfrequently, varies greatly. The equality required by the mechanical theory does not exist in nature.

It may not be out of place if I here give the results of some of my own observations and experiments on twining stems and tendrils. During two summers I have carefully examined the following: the twisted stems, shoots, and tendrils of the hop, convolvulus, honeysuckle, bean, gourd, cucumber, vegetable marrow, sweet-pea, passion-flower, &c.

In the cucumber, melon, vegetable marrow, sweet-pea, and passion-flower I found that the stems are twisted

in opposite directions, and the spirals formed by their tendrils form single and double reversing spirals (Plate x., p. 24; Plate cvi., Fig. 3; Plate cvii., Fig. 2, Fig. 3, B, C, p. 613).

The double twisting in the stems occurs in the internodes with or without a plain internode between (Plate cvii., Fig. 3, B, C). The twist is well seen in each case from the fact that the stems are all ridged, and the opposite twists can be traced without difficulty both by the sight and touch. In the round-stemmed passion-flowers it is more difficult to make out the double twist. This, however, can be done in most cases by peeling portions of the rind from the stem and watching the directions taken by the rind in the peeling process. It can also be ascertained by fixing the top of each internode with the finger and thumb of the left hand and twisting the lower portion of the internode by the finger and thumb of the right hand. A greater degree of torsion can always be obtained in the direction in which the internode twists naturally. By going carefully over the stem in this way the spiral reversals can generally be made out. If the stems of the passion-flower, sweet-pea, cucumber, and vegetable marrow twist in two directions and form double alternating right and left-handed spirals (which they unquestionably do), it is natural that the tendrils of these plants should also form double alternating right and left-handed spirals as apart from irritability and outside stimulation such as are assumed to be supplied by extraneous supports (Plate cvii., Fig. 2, p. 613).

As the four stems in question grow naturally in double reversing right and left-handed spirals, so do the tendrils of the four kinds of plants.

The double reversing right and left-handed spirals formed by the stem of the sweet-pea account for the tendril of the sweet-pea forming right and left-handed curves and spirals, and, in some instances, double reversing spirals (Plate cvi., Fig. 4, B, p. 612).

Speaking of tendrils, it may be well to note that the younger developing tendrils in the growing shoot of the vegetable marrow are rolled up into beautiful flat spiral whorls similar to those met with in white bryony. The whorls gradually uncoil and straighten, and the tendrils are then ready to form new and different kinds of curves and spirals with or without coming in contact with supports (Plate cvi., Fig. 3; Plate cvii., Fig. 2, pp. 612, 613).

The mature tendrils in the vegetable marrow proceed from a separate tendril stem, and may be two, three, four or five in number. They vary in size and degree of coiling according to age. Thus the youngest tendril may be straight, the second youngest slightly curved, the third youngest forming a spiral loop, the fourth youngest a spiral with the coils all running in one direction, the fifth or oldest forming a double reversing right and left-handed spiral. The coiling does not always begin at the apex of the tendril. Thus in the passion-flower, in quite a large number of cases, it begins a couple of inches or so from the base of the tendril (Plate x., Fig. 1, A, B, C, p. 24).

One would naturally have expected that the coiling would always have taken place at the tip of the tendril, but this is not the case. The tip of the tendril, in making a single simple spiral with the coils all running in one direction, or a double reversing right and left-handed spiral, seems to wind round and round while the spiral or spirals are being formed. The spirals in many instances are formed by the curving and coiling of the comparatively fixed basal portions of the tendrils, and not by the free untrammelled apical portions. The basal coiling can only be the result of a vital process. It may consequently be taken for granted that the fixing of the free extremity of a tendril has nothing to do with *the production of the double reversing, alternating, right and left-handed spirals.*

I will now briefly describe the appearance presented by the stems, shoots, and tendrils of the passion-flower, sweet-pea, cucumber, and vegetable marrow. And first the passion-flower.

§ 197. Spirals formed by the Tendrils of the Passion-flower.

I carefully examined four different varieties of this plant.

The stems plainly twist in two directions: the tendrils vary from six to eight inches in length; those at the summit of the plant being straight, with a slight tendency to curl and hook at the free end: the tendrils are very sensitive, and bend slightly on handling. The young unattached summit tendrils curl for the most part in one direction; but there are many cases in which the unattached tendrils form double reversing spirals. In these instances the coils on either side of the straight portions, where the reversals occur, are unequal: thus I found one unattached tendril with five basal coils, a reversal, and eighteen apical coils.

I found another unattached tendril with two basal coils, a reversal, and eight apical coils; the free end of the tendril forming a beautiful small terminal whorl which had evidently never seized anything. Another unattached tendril had three basal coils, a reversal, and twelve apical coils; another unattached tendril had six basal coils, a reversal, and eighteen apical ones. In a portion of a passion-flower stem which I examined there were nine coiled tendrils. Of these only one tendril was fixed to a support, and two tendrils had caught their own stem. One of the caught tendrils had five basal coils, a reversal, and six apical coils; the second had two basal coils, a reversal,

and two apical coils. Of the free or unattached tendrils, one, near the summit of the stem, had an open conical spiral of eight coils. The next unattached tendril had a spiral composed of two basal coils, a reversal, and twelve apical coils. The next unattached tendril, lower down the stem, had a spiral of eleven basal coils in one direction; the spiral ending in a tangle. The next unattached tendril had twenty-four coils all in one direction, and no tangle. The next unattached tendril still lower down the stem had a spiral with fifteen coils in one direction, a reversal, two turns in an opposite direction, and a tangle. In the lowest unattached tendril there was a spiral consisting of five basal coils, a straight portion, a reversal, and twenty apical coils. The portion of the stem referred to was growing and moving freely in space.

From the foregoing, it will be evident that single and double reversing spirals are found indiscriminately in the passion-flower. This means, that the tendrils have the power of reversing their spirals apart from contact and fixing; in fact, the reversing is a natural process due to life, growth, and pre-arrangement. The reversing of the coils is most probably an attempt on the part of the plant at symmetry; single spirals being invariably lop-sided.

Where tendrils are fixed at their free extremities, I find that the number of coils on either side of a reversal is, in some cases, equal, but in others markedly unequal. The unequal coiling is, on the whole, the more frequent. Then, as stated, there are cases where there are many reversals. In one spiral I found five basal coils, a straight portion, then a reversal and six coils, then a reversal and two coils; the apical portion of the tendril then winding round the stem of the passion-flower. This raises the question, Can the stem of a climbing plant possibly act as an irritant or supply a stimulus to its own tendrils? I do not think so. The fact that tendrils reverse more than once, even when not fixed, points to a natural vital provision, *as one reversal* would have sufficed to meet the mechanical view of Mr. Darwin and Professor Sachs. Nor must it be overlooked, that the mechanical view of reversals in the tendrils would not meet or explain the reversals in the internodes in twining plants where the summits of the plants *are not fixed*. The coiling and spiral twisting of the tendrils form beautiful, very highly elastic springs which can be drawn out to a great extent and recoil and assume their former shapes without breaking or being injured in any way. I found one *free* tendril within four inches of the summit of a passion-flower which had coiled loosely round its own stem. This free tendril formed a very wide open spiral. It made two turns at its basal portion, reversed, and then made three turns with its apical or loosely-fixed portion. The coils (and this is important) were so open that there could be no mechanical necessity for reversing, as there could be no danger of the tendril being hurt by being screwed up or fixed at any given point. I am therefore forced to conclude that the reversing is a vital, and not a mechanical process (Plate cvi., Fig. 3, p. 612; Plate x., Figs. 1 and 2, p. 24).

The foregoing was confirmed by a careful examination of other specimens of passion-flower.

Specimen two.—This specimen had two straight-growing summit tendrils. The third tendril, three and a half inches long, made a large open curve; the fourth tendril, five and a half inches long, made an open coil with its free end half an inch in diameter; the fifth tendril, eight and a half inches long, and unattached, formed a double reversing spiral consisting of two basal coils, a reversal, and four and a half apical coils. This tendril made large open coils, doing away with the necessity for reversing. The sixth tendril measured ten and a half inches in length. It was unattached at its free extremity. Its spiral consisted of one basal coil, a reversal, and another coil; then a second reversal, another coil, and then a whorl. The basal coil was an inch in diameter; the reversal seven-eighths of an inch across; the coil beyond, half an inch; the second reversal three-eighths of an inch across; the coil beyond, rather under a quarter of an inch. Here we have a pyramidal unattached spiral with coils so large as practically to make a rupture of the tendril impossible. The reversal in this case cannot be the result of mechanical torsion as described by Mr. Darwin and Professor Sachs. The seventh, eighth, and eleventh tendrils had caught each other and made a tangle. The seventh tendril made a reversal and a coil before it reached the tangle. The eighth tendril made six basal coils, a reversal, and five apical coils before it reached the tangle. The ninth tendril was unattached, and straight for two and a half inches, and ended in a round-shaped tangle. The tenth tendril, which was unattached, had a straight stem of two and a half inches, and ended in a double or reversed spiral; the spiral consisting of two basal coils, a reversal, and seven coils, then a second reversal, and six coils, then a third reversal, and an apical coil of a turn and a half. The eleventh tendril made five basal coils, a reversal, and five apical coils; then a waved part one and a half inches in length, then a little tangle of its own, and then the large tangle.

Specimen three.—In this there were three growing summit tendrils. The highest tendril measured two inches, and had a slight double or alternating curve. The tendril below it measured five inches, and at its tip had made one open coil fully a quarter of an inch in diameter. The third tendril (still going down the stem) measured eight inches. It was unattached, and had a long, nearly straight stem six inches long, at the end of which was a spiral consisting of one basal coil, a reversal, and four apical coils. This tendril had evidently never been attached to anything, yet here

was the reversal in anticipation of catching on. The spiral reversing movements of the tendrils are clearly natural. The reversals are evidently not the result of irritability or contact.

The fourth tendril had a straight stem of three inches, and made an open curve one inch in diameter, and terminated in a conical spire. This I carefully unravelled. It consisted of a spiral with seven basal coils, a reversal, and five apical coils. If I had not unravelled the conical spire referred to, I would have said it consisted of one spiral, all the coils of which ran in the same direction. Here again the reversal was natural. The fifth tendril was also unattached. It made a large open coil three-quarters of an inch across; the coils gradually becoming smaller. I unravelled it, and found it consisted of a spiral with two basal coils, a reversal, and four apical coils. The sixth tendril was unattached, and measured eleven inches in length. It had a stem two and a half inches long, and made large open coils; the spiral running in only one direction. The seventh tendril was unattached. This had a straight stem of three inches. It then formed a spiral consisting of four basal coils, and two reversals or straight portions, the one directed away from, the other towards, the spectator; three coils running in the same direction as the basal coils, a second reversal, and five apical coils running in an opposite direction. Here again the reversals could not be due to contact and the fixation of the free end of the tendril. The reversal of the spiral is evidently arranged for as apart from irritability, contact, and fixing. The eighth spiral was unattached. This had a straight stem two and three-quarter inches long, and ended in a spiral consisting of five basal coils, a reversal followed by one coil in an opposite direction, a second, third, and fourth reversal, followed by a coil of five and a half turns running in the same direction as the basal coil. Here again the reversals must be regarded as natural and non-mechanical.

Specimen four.—In this specimen I got similar results. The tendril nearest the summit was *unattached*, and formed a double spiral, which consisted of four basal coils, a reverse, four coils, a second reverse, and four apical coils. The second tendril was unattached, and formed a spiral with seventeen coils, all running in the one direction. The third tendril had doubled back upon itself, and made a spiral and tangle round its own stem. The fourth and fifth tendrils were unattached, and had caught each other and made a slight tangle. Tendril four made a spiral with four reversals, the coils being from one to three in number.

Specimen five.—This specimen resembled the others, and need not be separately described. As a result of these examinations I have come to the conclusion that a comparatively large number of free or unattached tendrils form spirals running in two or more directions; the spirals running in one direction being rather the exception. To prove this point each spiral must be carefully unravelled and examined, not in a coil or in a tangle. This precaution does not seem to have been previously taken.

§ 198. Spirals formed by the Tendrils of the Sweet-pea.

The stem of the sweet-pea affords a striking example of a double reversing spiral. Its pronounced, outstanding spiral ridges or flanges at once attract the eye and rivet the attention. The direction of the spiral is reversed at almost every internode, so that if one internode forms a right-handed spiral, the internodes above and below form left-handed spirals.

The tendrils of the sweet-pea are arranged on either side of the stem near its summit, or on subsidiary stems. They not unfrequently crown a stem or branch, in which case they are provided with a tendril stalk from which two, three, or more short tendrils proceed. The tendrils form graceful, open spirals, some of them of the crozier pattern. The spirals are right and left-handed like the stem. It happens occasionally that a tendril makes one or two spiral coils in one direction and then reverses and makes two or more spiral coils in an opposite direction. The tendrils are thus true to their prototype, the stem. The arrangement is illustrated at Plate cvi., Fig. 4, B, p. 612.

§ 199. Spirals formed by the Cucumber.

The stem of the cucumber is twisted in two directions like that of the sweet-pea. The spirals formed by its tendrils greatly resemble those made by the passion-flower. In the two specimens which I examined the tendrils developed several double reversing spirals. In one tendril, which had caught a cucumber leaf with its basal and central portions, I found the following on carefully uncoiling the spiral: a basal coil of three turns, a reversal, a coil of three turns, a second reversal, a coil of five turns, a third reversal, a coil of four turns, a fourth reversal, and an apical coil of five turns. This tendril, as stated, had seized the leaf by its basal and central portion; *its apical portion being quite free.* It follows from this that the reversals are not caused by the fixing of the free end of the spiral, which Mr. Darwin and Professor Sachs regard as a necessity.

§ 200. Spirals formed by the Tendrils of the Vegetable Marrow.

The stem of the vegetable marrow reveals the double, alternating, opposite spirals witnessed in the passion-flower, sweet-pea, and cucumber. Its tendrils afford perhaps the best examples known of spirals and spiral coils which run in one or several and opposite directions (Plate cvi., Fig. 3, A, B, C; Plate cvii., Fig. 2, A, B, pp. 612, 613).

If the summit of a growing shoot of vegetable marrow be carefully examined, from ten to fifteen tendrils rolled up into exquisitely coiled flat spires, like ammonites, will be discovered.[1] A most interesting physiological point emerges here. The tendrils are at first closely coiled up. They then uncoil and straighten. In this condition they are ready to seize upon supports. They subsequently coil a second time, with or without supports. The first coiling certainly cannot be due to irritation and external stimuli. Neither can the second coiling, as it occurs in the absence of supports. In both cases, the coiling can only be due to vitality and spiral growth.

These tendrils are compound in the sense that from two to six tendrils spring from a common stem or peduncle, and are in various stages of development. Some of the tendrils springing from the same peduncle form right-handed, others left-handed spirals. They are rolled up as they grow from base to apex, the delicate growing extremity of each tendril being found in the centre of the spiral coil, where it is daintily protected. Original drawings of these tendrils are given in the Plate mentioned above.

As the tendrils develop, the peduncle or common stem thickens, and they gradually uncoil until they assume the appearance of long, slender, straight, slightly wavy filaments. At this stage they are highly sensitive, and in a condition to seize anything in their vicinity, or to coil up into single spirals with the coils all running in one direction, or into double, reversing spirals, with the coils running in opposite directions.

The history of the tendrils of the vegetable marrow is at once interesting and instructive. They appear as scarcely visible points, and are from the first coiled up. As they increase in size their spiral form becomes more pronounced and more beautiful. Their spiral structure is unquestionably due to life and growth, as apart from irritability, stimulation, or contact with a foreign body. By-and-by the exquisitely-coiled tendrils straighten. This they do spontaneously, and quite apart from irritability and artificial stimulation. They are living, growing things. At a later stage they re-coil and form single spirals with the coils all running in one direction, or double reversing spirals with the coils running in opposite directions. In the later stage, they may or may not seize foreign substances as supports, but whether they do so or not their movements are spontaneous and inherent, and are not caused by irritability, artificial stimulation, or contact with foreign bodies. The life and directive agency assert themselves equally in the earlier and later stages. The tendrils seize extraneous supports without any help from the foreign substances seized.

When the tendrils are maturing, the common stem from which they spring measures from one to four or five inches in length; some of the tendrils attaining a length of from ten to twelve inches. The stems and tendrils are longest near the growing shoot. The tendrils, whatever their number, are of different ages, sizes, and forms. Thus in one stem with a bunch of five tendrils which I examined, one tendril was straight; a second was slightly curved and formed a terminal open coil; a third formed a true spiral consisting of a few open coils; a fourth formed a closer and more extensive spiral with the coils all running in the one direction; the fifth forming a double reversing spiral with the coils alternating and running in opposite directions.

I examined a large number of specimens with the following results:—

One of these consisted of a stem with a terminal shoot. Near the summit of the shoot there was a typical cluster of tendrils, five in number, arranged on a tendril stalk: one tendril was straight; a second made a spiral of a coil and a half; a third made a spiral of two and a half coils; a fourth of four coils. These four tendrils made simple open spirals, the coils all running in one direction. There was this peculiarity: two of the tendrils made right-handed, the other two left-handed spirals. The fifth tendril had caught some blades of grass, and made a reversing spiral consisting of six basal coils running in one direction and eight apical coils running in an opposite direction. It was the apical coils which had seized the grass. In another tendril, which had also caught some blades of grass very closely and tightly with its terminal coils, the spiral consisted of six basal coils, a reversal, and six apical coils, and a tangle.

In another tendril, which had also caught grass, the spiral consisted of one coil, a reversal, another coil, a second reversal, and then a coil ending in a tangle which I unravelled. The ravelled or tangled portion of the tendril made spirals similar to those made by the unravelled portion.

In another specimen examined, the tendril stem gave off five tendrils: of these one was short and straight (the youngest); a second made a turn and a half of a spiral with its terminal end; a third made a spiral of two and

[1] The ammonite and tendril grow in opposite directions. The ammonite grows by additions to its base—the tendril by additions to its apex.

a half turns. The spirals made by tendrils two and three ran in one direction and formed left-handed spirals. The fourth tendril made a spiral of five coils; the coils running from right to left of the spectator. The fifth tendril made a double reversing spiral consisting of seven coils, a reversal, and eight apical coils. This tendril had caught some decayed blades of grass. In the summit or growing part of this specimen there were two tendril stems, each bearing four tendrils. In each cluster of tendrils there was a long, straight tendril; the other three in each being coiled up in open spirals like the fronds of a fern. The spiral coils ran in opposite directions. In a cluster of four tendrils, two generally form right-handed, and two left-handed spirals.

In a third specimen examined, three tendrils proceeded from one tendril stem. Of these one was unattached, and made an open tapering spiral coil of four and a half turns; the spiral running from right to left of the spectator. The second tendril, also unattached, made a double reversing spiral consisting of one coil, a reversal, one coil, a second reversal, one coil, a third reversal, one coil, a fourth reversal, and three terminal or apical coils. All this in an unattached tendril is remarkable. The frequent reversals were plainly not the result of irritability, artificial stimulation, or fixation.

The next tendril examined had attached itself by its distal end to six blades of grass, which it grasped very tightly. It formed a double reversing spiral consisting of six spiral coils (conical in shape), a reversal, eight coils, and a tangle, within which the grass was firmly clasped. I undid the tangle and liberated the grass and found the spiral reversed a third time; the apical coil consisting of three and a half turns. In one *unattached* tendril which I examined there were no fewer than eight reversals. When the reversals are numerous the coils between them are, as a rule, few in number.

The tendrils of the vegetable marrow are frequently very long, one of them measuring eighteen inches. A curious feature about tendrils is that they coil ever and anon upon their own stems and upon themselves. They also occasionally coil themselves into knots; at times the apical portions thread or run through one or more coils. Tendril tangles, some of them very complicated, are by no means uncommon.

A vigorous tendril which had caught some blades of grass with its free end made a spiral consisting of six coils running from right to left of the spectator, a reversal, ten coils running from left to right of the spectator, a second reversal, twelve coils running from right to left of the spectator, a third reversal, and three coils running from left to right of spectator.

The *unattached* tendrils in the vegetable marrow rarely have spirals running all in one direction. The rule is for the spiral to reverse, unless in the very young spirals, which are just beginning to re-coil; but in these, as already pointed out, there are right and left-handed single spirals.

The relation of the single and double spirals of climbing plants to vegetable and animal spirals generally is fully illustrated at Plate cvi., p. 612, where typical examples of plant and animal spirals are given.

PLATE CIX

Plate cix. illustrates the several kinds of spirals (single and double) found in plants and animals, and parts thereof.

FIG. 1.—Vigorous spiral shoot of *Menispermum canadense* grown without a support. The shoot has been deprived of its leaves, flowers, and hairs. The vertical line (f, g) represents an imaginary axis. The shoot crosses the axis from left to right, and forms an open left-handed spiral. a, Top of plant; b, c, d, e, spiral bends or curves made by the plant (after Sachs).

FIG. 2.—Apex of a shoot of *Akebia quinata* which has grown out beyond the support and formed free spiral coils in the air (Sachs).

FIG. 3.—Shoot of axis of white bryony (*Bryonia dioica*) with petiole (b), bud (k), hairs (f), and tendril forming double reversing spirals (u, v, w); the free end of the tendril having curved round a branch (A) at the point x (Sachs).

FIG. 4.—*Sipunculus nudus* laid open from the side, showing left-handed spiral intestine (a). b, Anus (after W. Keferstein). Resembles spiral umbilical cord (Fig. 3, Plate xii., and spiral hop stem (Plate x., Fig. 2, A, B, p. 24).

FIG. 5.—"A. Transverse section of a revolute leaf. The two edges are rolled outwards or away from the axis.
"B. Transverse section of an involute leaf. The two edges are rolled inwards or towards the axis.
"C. Transverse section of a convolute leaf. The leaf is rolled upon itself so as to form a continuous coil.
"D. Transverse section of a plicate or plaited leaf. The parts of the leaf are folded together like a fan.
"E. Circinate vernation, in which the leaf is rolled up from apex to base like a crozier.
"F. Diagram to illustrate contorted or twisted æstivation, in which the parts of the whorl are overlapped by each other in turn, and are twisted on their axes as in the mallows.
"G. Diagram of the flower of the sowbread (Cyclamen) showing the five sepals overlapping each other, and five petals arranged in a contortive manner, five stamens, and a pistil in the centre" (Professor J. Hutton Balfour).

FIG. 6.—A, B. Diagrams illustrating the spiral arrangements of the leaves on the stem of a plant. At A, the divergence between every two leaves is $\frac{3}{7}$ as shown by the upper circle of the diagram, where the space between 1 and 2 includes three of the seven divisions. At B, the divergence between every two leaves is $\frac{1}{7}$, as indicated by the marks on the circle.

C. Spiral fir cone—the spirals running in two principal directions, as shown by the darts; the one spiral being more vertical than the other. The secondary spirals indicate the difference between each scale of the cone in a single spiral. The cone is composed of numerous scales, which are metamorphosed leaves arranged on a common axis and covering the seeds (after J. H. Balfour).

PLATE CIX


Fig. 1.
Fig. 2.
Fig. 3.
Fig. 4.
Fig. 5.
Fig. 6.
Fig. 7.
Fig. 8.
Fig. 9.
Fig. 10.
Fig. 11.
Fig. 12.

PLATE CIX (*continued*)

FIG. 7.—A, B, C. Spiral vessels from *Sambucus ebulus*. Magnified 400 diameters (Henfrey).
D. Cells of a filament of *Spirogyra*, with spiral green bands. Magnified 200 diameters (Henfrey).

FIG. 8.—A. Trachea or breathing tube of insect composed of spiral fibres.
B. Egg of *Diplozoon* displaying delicate, terminal, hair-like, spiral fibres (after Zeller).

FIG. 9.—Shows spiral development of human heart.
A. Earliest form of fœtal heart. *a*, Venous extremity ; *b*, arterial extremity.
B. Fœtal heart twisted upon itself. *a*, Venous extremity ; *b*, arterial extremity.
C. Fœtal heart divided into right and left cavities. *a*, Venous extremity ; *b*, arterial extremity ; *c*, *c'*, pulmonary branches (after Dalton).

FIG. 10.—A. Oogonium of Chara entire, composed of five cells wound round a large central cell in a spiral manner, with corona (*a*).
B. Spiral spermatozoid of Chara separated from a cell. Shows two vibratile cilia (after J. H. Balfour).
C. Fossil carpogonia of Chara. *b*, Side view of *Chara lemani*, × 10 ; *c*, under view, showing spiral arrangement of cells.
D. *Chara medicaginula*, × 10. *d*, Side view ; *e*, under view, showing spiral arrangement of cells.
E. *Chara helicteris*, × 10. *f*, Side view ; *g*, under view ; and *h*, top view, showing spiral arrangement of cells ; *i*, one of the spiral cells detached (after Cuvier).
The spirals shown at D and E of this figure resemble the spirals seen in nebulæ (Plate viii. p. 17), certain shells (Plate xiii., Fig. 1, F, G, p. 28), certain cones (Plate xi. Fig. 1, bottom row, p. 25), and the apex of the heart (Plate lxxxv., Fig. 8, p. 325).

FIG. 11.—Corkscrew sea fan (*Streptocaulus pulcherrimus*). Forms elegant right-handed spiral (*a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*).

FIG. 12.—" A. Spiral cell, or cell with a spiral fibre inside, from an orchid.
" B. Spiral vessels taken from the melon, showing the elastic fibres uncoiled.
" C. Vertical section of the seed of Bunias, with its spiral embryo. The cotyledons are rolled upon the radicle in a spiral manner, hence the name spirolobeæ.
" D. Exogenous stem, surrounded by a woody climbing plant (bush rope) which causes contractions and swellings of the stem.
" E. A stem with alternate spiral leaves arranged in a quincuncial manner. The sixth leaf is directly above the first, and commences the second spiral cycle " (Professor J. Hutton Balfour).

DESIGN IN CLIMBING, SENSITIVE, AND INSECTIVOROUS PLANTS

It would be difficult, if not indeed impossible, to find better examples of design than are furnished by climbing, sensitive, and insectivorous plants. In these we have a series of remarkable adaptations of a minute and far-reaching kind, which cannot be satisfactorily explained either by spontaneous generation, evolution, or so-called natural selection. The modifications and arrangements are of such a character as absolutely to demand the operation of intelligence, either directly or indirectly, at some period or other. The actions of the plants in question are purposive to a degree, and as the plants themselves cannot be credited with the requisite knowledge to bring about the definite results attained, we are bound to fall back on a Creator and Designer Who works in and through the plants.

When climbing plants throw out rootlets, suckers, hooks, elbows, kinks, &c., from their stems, leaf-stalks, and leaves, or when they wind themselves round living or dead vertical supports stronger than themselves, they take advantage of engineering principles of which they can have no direct or immediate knowledge. The same is true of plants which climb by the aid of tendrils. The object in all cases is to attain a higher altitude, and so procure more sun, more light, and more air than they could obtain as apart from climbing.

When a pitcher plant inveigles into its urn-shaped pitchers (by fragrant scents and attractive juices) flies, beetles, and all sorts of creeping things, and when, further, it overpowers by its gases and fluids the hapless intruders so that they die, decay, and, being absorbed, form food, the plant exercises the wiles of the professional trapper and hunter. But the pitcher plant cannot be credited with the knowledge necessary to produce the extraordinary sequence of events which prove so beneficial to its economy and general well-being.

When Venus's fly-trap spreads its flat, bi-lobed, hinged leaves, each of which is supplied with a formidable fringe of small spikes at its margin and six slender, highly-sensitive central hairs, it cannot know that small insects of various kinds will crawl over its leaves, and yet, as soon as the insects and other marauders put in an appearance and touch the sensitive hairs, it at once exercises the means of capturing them. It instantly closes its bi-lobed leaves on the unsuspecting prey, and before the prey is aware it is fatally imprisoned. Nor does the matter rest here ; the leaf exudes an acid secretion containing a ferment, and the ill-fated insect or other creature which has been caught and crushed is digested, absorbed, and finally assimilated. Here the plant not only catches but devours higher organisms than itself.

The performances of the sundew are still more astounding. This extraordinary plant not only sets a trap for insects and other small creatures, but daintily baits the trap. The leaves of the sundew are provided with some two hundred amazingly sensitive hair-like processes or tentacles, each of which terminates in a small, oval-shaped gland which exudes a bleb of very viscid secretion which glistens like dew, and which is most attractive to insects and

other small animals. The highly sensitive hairs or tentacles are further endowed with spontaneous, independent movements, whereby they can transmit to the centre of the leaves anything which alights on or crawls over them. In addition, the glands of the plant provide a digestive secretion, not unlike the gastric juice of our own stomachs. Here is a veritable battery of design ; a series of modifications and adaptations of means to ends, which, as apart from intelligence, is utterly inexplicable. The sundew literally lays itself out for attracting, seizing, and devouring insects, and in this it succeeds to quite a marvellous extent. The glistening secretion produced by the terminal glands of the hair-like tentacles is the first step towards capture ; that entices, clogs, and entangles the wings and feet of the prey. The second step consists in the progressive, co-ordinated, bending movements of the tentacles whereby the prey is conveyed to the centre of the leaves. The third step consists in the exudation from the glands of the leaves of an acid secretion containing a ferment akin to gastric juice, which digests the prey and results in its absorption and assimilation. That the sundew is intended to feed largely by its leaves, in the manner indicated, is proved by the small size and inadequacy of its roots, and from its being found on heaths and poor impoverished lands which offer a scanty and precarious food supply.

In the case of the sundew, the structure and function of the plant are so obviously purposive that the intelligent adaptation of means to ends must be frankly admitted. The capturing acts of the plant are to be placed in the same category as those of the fowler who sets up his decoy bird, with its environment of bird-lime twigs, or hair loops for securing the feet of the unsuspecting birds of the neighbourhood. The plant cannot possibly realise the import of the successive steps of the capturing process, so that we are forced to fall back on the intelligence of the Creator or First Cause Who supplied the plant with its several structures so accurately adapted to the discharge of the particular and peculiar functions referred to. No form of spontaneous generation, and no amount of evolution or so-called natural selection, however long the period allowed, could possibly produce the sundew of the present day. Neither could irritability of constitution, extraneous stimulation, and environment culminate in such an unlooked for and wonderful transformation.

Those who believe in spontaneous generation, evolution, and natural selection have to account for life, for special structures, and for special functions which cannot possibly be the result of chance efforts, however frequently repeated or however long continued.

It is easy to construct theories and coin phrases. It is quite another thing to prove that the theories are correct and that the phrases convey a definite meaning. Spontaneous generation, evolution, natural selection, and the survival of the fittest (the last a phrase first introduced by Mr. Herbert Spencer) are one and all hypothetical. Life, even in its simplest forms, cannot begin of itself ; evolution implies and necessitates involution ; natural selection demands a Selector outside the plant and animal ; and survival of the fittest, in the sense in which it is commonly employed, is a mere truism. The fittest would and do survive, apart either from evolution or natural selection.

The climbing, sensitive, and insectivorous plants focus and crystallise, so to speak, properties common to plants in general. All plants may be said to be under the influence of light, heat, moisture, and climate. They are also susceptible to the influence of good, bad, and indifferent food, whether gaseous, liquid, semi-solid, or solid. The same is true of animals. All plants are sensitive in a sense ; they are, moreover, more active during the day than during the night, and in spring and summer than in autumn and winter. Some plants sleep and fold their leaves and flowers during the night ; they practically hibernate during the winter as many animals do. The sensitive plants respond to the touch by very marked movements of their leaves, leaflets, and leaf-stalks. In a word, all plants are designed for, and adapted to, their surroundings and environment just as animals are. Were it otherwise, neither plants nor animals could exist. If plants and animals, from the lowest to the highest, had to wage an incessant warfare with the forces of nature, they would inevitably succumb to the inimical conditions to which they are continually exposed ; they would succumb as adults in their strength, and especially at their advent or birth, their period of tenderness and weakness. The theory of the struggle for existence is alike unnatural and untrue. It takes for granted that nature is in a state of chronic warfare, and that her provisions for her living things are imperfect, inadequate, and parsimonious to a degree. In reality it is quite otherwise ; the opposite is nearer the truth. The plenitude of nature is proverbial. She is lavish in everything. She is especially lavish in all that pertains to the food supply, as shown in the vast numbers of seeds and eggs, and the plethora of young things produced by plants and animals alike. These are to be counted by millions. If there is overcrowding of plants and animals in certain districts and at particular periods it is the exception rather than the rule. The scheme of life involves a corresponding scheme of death, for everything lives on every other thing, but there is nothing which savours of scarcity and starvation in the comprehensive, all-satisfying plans of nature. The superabundance of food on sea and land, in a state of nature, completely negatives the "struggle for existence" theory, and it is a mistake to reason from special instances of overcrowding that the supply of food is not generally, and as a rule, equal to the demand when the whole scheme of nature is taken into account and all the circumstances duly considered.

That thousands of small, ill-grown plants and animals occur occasionally in certain districts and at certain times is no proof that there is not room for the great races of plants and animals on the earth, or that they are habitually starved and have to struggle for life. If this were so, it would be difficult to find anywhere a healthy, well-fed plant or animal, which is just the reverse of the truth. Starved and diseased plants and animals in nature are the exception. Moreover, where overcrowding and partial starvation occur, the plants and animals best fitted for the locality, and for the particular period, have the pull, and are, so to speak, accorded preferential treatment. Everything works together for good, and overcrowding very soon cures itself. Only the plants and animals intended to survive do survive; but their survival is not left to minute and trifling chance modifications and adaptations extending over a practically unlimited time, as stated by Mr. Darwin. The theory of natural selection and "the survival of the fittest" proceeds on the assumption that plants and animals, from the lowest to the highest, possess the power of selecting, perpetuating, and accumulating slight chance differences and modifications which are supposed to be beneficial to themselves, to the exclusion of other modifications which are believed to be prejudicial. As I explain elsewhere in this work, no plant or animal possesses this power. No plant or animal can control the amount or direction of its growth; even man cannot add to or take from his stature; he cannot even quicken or delay the growth of a single hair: neither can a plant or animal control its functions. The flow of secretions and the discharge of excretions and other fundamental arrangements are, for the wisest of purposes, placed beyond the reach of the plant and animal. Plants and animals, in a state of nature, are controlled by a Power outside of, and, so to speak, beyond and behind them.

In the case of the insectivorous plants, the structures composing the plants grow naturally in the process of development. The plants are what they are, not by accident but by design. The adult plants are completed wholes; that is, the plants consist of several distinct parts, and each part discharges a particular and well-defined function. There is nothing to show that the sundew, for example, began its career by suppressing its roots and differentiating its leaves; that it chose to grow in waste places where root food was scarce and insect and leaf food abundant; that it perceived that it would be to its advantage to develop on its leaves some two hundred highly sensitive hair-like processes or tentacles with spontaneous co-ordinated movements for seizing insects of various kinds; that it would be a further advantage to develop glands on the tips of the tentacles to produce, at one time, a glistening viscid secretion to attract insects to the leaves; and, at another time, an acid digesting secretion which is practically a form of gastric juice, to digest the insects enticed, entangled, and secured by the formidable array of baited tentacles. It goes without saying, that the sundew had no power at any period of its history to produce the machinery required for enticing, capturing, digesting, and assimilating insects and other tiny living things. In nature, the carnivorous animals are endowed with an intelligence and courage superior to their victims. The superior intelligence of the flesh-eaters is necessary to enable them to circumvent their prey. In the case of the sundew, however, we have a plant, with no intelligence proper, circumventing, seizing, and devouring organisms much higher than itself. If the intelligence necessary to the accomplishment of these ends cannot be traced to the plant, it is obvious it must be sought in the Maker, Designer, and Upholder of the plant. The endless array of accidental trifling modifications and adaptations required, according to Mr. Darwin, to build up the higher plants and animals have, as a matter of fact, no existence. The theory of natural selection implies that plants and animals are their own designers and architects, which they are not. It ignores the important fact that in every instance plants and animals are conditioned and their sphere of activity limited; that they are made to occupy and to dwell in certain localities at stated times; that they cannot transplant themselves at discretion in space and time; that they are adapted to certain environments of climate, light, heat, moisture, food, &c.; that everything which lives has the power of reproducing itself, each according to its kind, and is endowed with the property of persistency and permanency as regards type which proclaims a reign of law and makes confusion and failure impossible. The chance variations to which so much importance has been attached of late years are, in reality, mere "asides" in the histories of plants and animals, and are of practically little or no value in the great scheme of creation, which is governed by law and order, and not by chance and rule of thumb, as many modern scientists affect to believe.

§ 201. Growth in Plants and Animals.

Growth is of several kinds, but in every case its direction and extent are predetermined. It may be molecular or cellular in its nature. Thus a multicellular plant or animal may divide and subdivide and give rise to new individuals, or a unicellular plant or animal may by fission, budding, or analogous processes multiply itself indefinitely. In plants, growth and reproduction may also be effected by seeds, roots, branches, leaves, &c., which are integral parts of the whole. In animals they may be produced by the union of separate male and female elements situated on the same or different individuals; a statement which also holds good of plants.

However reproduction and growth are inaugurated, they are to be regarded as fundamental and persistent in their nature, and the organisms sooner or later take the precise forms of their predecessors or progenitors, which is equivalent to saying "like begets like," both in the vegetable and animal kingdoms.

Reproduction and growth proceed on definite lines, and there is, in every instance, a tendency to the repetition of parts. This repetition assumes a great variety of forms. Thus there are :—

(*a*) Longitudinal division or branching.
(*b*) Transverse division.
(*c*) Radiation from a centre, stellate fashion.
(*d*) Radiation from a centre in increasing circles.
(*e*) Curves of various forms.
(*f*) Symmetrical spirals which usually overlap but do not interlock.
(*g*) Combinations of two or more of *a*, *b*, *c*, *d*, *e*, and *f*.

Examples of (*a*) are seen in the breaking up of a plant into branches and of an animal into limbs, bronchial tubes, blood-vessels, &c. Examples of (*b*) are witnessed in the longitudinal and transverse division of the plant *Sarcina ventriculi* into little squares, and animals into articulate and vertebrate forms. Examples of (*c*) and (*d*) are encountered in the rays and rings of growth in the stems of plants and in the rays and rings of growth of certain shells (oyster, clam, and other common forms), the scales of fishes, &c. Examples of (*e*) are common in the curved surfaces which bound plants and animals, and examples of (*f*) are met with universally in plants and animals both in their embryonic and completed forms. They are found in large numbers in rudimentary plants and animals.

It is necessary to direct attention to the essential steps in reproduction and growth to show that nature repeats and reproduces herself from certain types, and that while two or more types may be blended in a special organism there is not an indiscriminate or endless mixing up of the types which evolution claims, which would result in ultimate disorder and confusion. In other words, evolution can only be regarded as developmental or partial.

Man, for example, cannot be evolved from an oyster even by infinite permutations and modifications in endless time. Further, species cannot be manufactured *ad libitum*.

The several races of plants and animals have their limits prescribed, and within these they must live and move. If man by *artificial* selection, and by interbreeding, produces what some are pleased to call new species of plants and animals, it must be borne in mind that the plants and animals improved by superior feeding, climate, &c., revert to their originals if left to themselves.

It has yet to be proved that there is such a thing as *natural* selection in plants and animals. Artificial and natural selection, in the Darwinian sense, are not to be placed in the same category. In the former, a Selector or intelligent Agent is required and His existence admitted : in the latter no Selector is required and His existence denied. If man selects and successfully crosses plants and animals, it does not follow that plants and animals can select and perpetuate the good properties and qualities in themselves to the exclusion of the bad properties and qualities. These are fundamental and not superficial distinctions.

If the vertebrate series of animals resemble the articulate in respect that they are divided transversely into more or less symmetrical segments, it does not follow that the vertebrates are the lineal descendants of the articulates. If further, the mammal *in utero* presents appearances met with in the adult fish, reptile, and bird, it is not thereby proved that a mammal is a transformed fish, reptile, or bird respectively. It only shows that nature has adopted certain types for plants and animals, and that she adheres to them as being the most convenient and best. If, again, man in his embryonic and fœtal stages resembles many other animals, it is not to be inferred that he is an evolution from animals far below him in the scale of being, such as the soft-bodied molluscs, or of mammals nearly related to him, such as the anthropomorphous apes.

The vertebrates are distinct from the articulates, and the mammals from each other, and endless modifications in endless time cannot make them identical in the matter of descent.

In making these statements I quite admit that there are resemblances structurally and functionally in plants and animals, and that the higher animals reveal traces of what are regarded by evolutionists as remnants of more rudimentary animals, but the particulars or premises are not in my opinion such as to justify the general conclusion that evolution is all embracing. It cannot, it appears to me, be made to include, and account for, the several races of plants and animals as we know them, and as they are revealed to us in the geological records.

The presence of remnants, so to speak, of structures in the higher animals which are well developed in the lower animals, such as the vermiform appendix in man, is indicative rather of a type than of actual descent.

The consolidation of the hoof of the horse to adapt it to the hard ground, and to prevent an unusual amount of wear and tear, is a mere adaptation of "means to ends," and an example of design. The fact that animals nearly allied to the horse have two bones in their legs while the horse has only one does not prove the descent of the one

from the other. The ox, sheep, deer, pig, &c., have the double arrangement of bones, and, as a consequence, are not so well adapted for treading the ground at high speeds and for carrying burdens. The camel forms an exception.

The solid hoof of the horse is prepared to deal with the hard, unyielding earth in the same way that the broadly expanded tail of the fish is prepared to deal with the yielding water, and the very greatly expanded wing with the still more yielding air. The structure is expressly formed for the performance of the function it is called upon to discharge. The function, however, does not produce the structure: the earth does not produce the small solid hoof of the horse, nor the water the expanded tail of the fish, nor the air the greatly expanded wing of the flying thing. While use and training develop existing structures, they cannot create the structures. Use and training, within limits, improve a structure, and disuse tends to deteriorate and destroy it.

The eyes of an animal kept continually in the dark become feeble. They even cease to be eyes in the ordinary sense, hence cave fishes as a rule are blind. Parasites degenerate structurally and functionally. They even lose their limbs and other important parts.

A distinction is clearly to be drawn between the use and disuse of organs. While, as indicated, use does not make organs, the disuse of them sooner or later impairs and ultimately destroys them.

THE UNIVERSALITY OF SPIRALS IN NATURE AS INDICATED BY STEREO-CHEMISTRY, &c.

I consider the importance of spirals such, that I devote no fewer than seventeen original plates (Plates cx. to cxxvi. inclusive) to their elucidation. The spirals, as explained further on, are divided into physical, vegetable, and animal.

The spiral seems to be inwoven in the very nature of things, and there are those who believe that the atoms, whatever their size, shape, and nature, obey spiral laws, and that matter, however finely divided, forms itself into eddies which display movements akin to those which we behold in the planetary system. There is, according to them, a cosmos within a cosmos. This part of the subject is too minute to admit of ocular demonstration, but the situation may be summed up by saying that all matter is in perpetual motion, and that the matter moves because of inherent and other powers in definite directions to given ends, which, in every instance, are predetermined. The matter and the movements are "means to ends," and are never haphazard. In growth, development, differentiation, and locomotion, the movements of matter are under restraint, guidance, and law. Even the size and shape of living bodies, especially organised spiral bodies, are regulated.

Plants and animals are symmetrical or unsymmetrical according as the spirals forming them are single or double, and according to the degree of spiral overlapping; the greater the amount of overlapping, the nearer the approach to symmetry.

The spirals in the physical universe are on a stupendous scale, as witnessed in sand-storms, cyclones, whirlpools, waterspouts, and spiral nebulæ, and inorganic spirals of small size are met with in crystals. The organic spirals abound in plants and animals, but all of them, whether organic or inorganic, bear a general resemblance to each other, showing a common origin and a community of function. Spiral tendrils, in some respects, resemble hands and feet, and climbing plants generally possess the latent properties of limbs. Not a few plants in their young condition utilise their spiral structures as organs of locomotion, and in the higher animals locomotion becomes a marked feature of existence. In the higher animals walking, swimming, and flying are all performed by the aid of distinctly spiral organs: the bones of the bodies and limbs being twisted upon themselves in a variety of ways, and employed as single and double figure-of-8 reversing curves (Plate cxxvi., Figs. 1 to 9), which confer continuity of movement and ensure great balancing power.

Spirals, unlike circles, when growing never cover exactly the same ground: they, therefore, represent advance and progress—the progress being advance in space in the case of the inorganic kingdom, and growth and differentiation and other movement in the case of the organic kingdom. The movement and growth, whenever and wherever they occur, are always limited and under control. They are never allowed a free rein. They afford admirable examples of "means to ends."

The great importance of spirals in the inorganic and organic kingdoms can scarcely be exaggerated. I have carefully examined the majority of them, and in addition have experimented largely with models, showing how single and double spirals can be produced and how they can be rendered permanent by employing certain materials, such as thin strips of sheet lead, and also copper and other ductile wire. The metals and other materials employed I

twisted and coiled in a great variety of ways, as shown at Plates cxi. and cxii. Examples of inorganic spirals are given at Plate cx., Figs. 1 to 6.

The subject of spirals in their ultimate relation to matter was discussed from the stereo-chemical point of view at considerable length by M. Pasteur. His argument naturally falls under "*Origin of Spiral Structures*," and is briefly as under: "Optically active substances may be divided into two classes. Some, like quartz, sodium chlorate, and benzol, produce rotation only when in the crystalline states; the dissolved (or fused) substances are inactive. Others, like oil of turpentine, camphor, and sugar, are optically active when in the liquid state or in solution. In the former case the molecules of the substance have no twisted structure, *but they unite to form crystals having such a structure.* We may build up a spiral staircase—an asymmetric figure—from symmetric bricks; when the staircase is again resolved into its component bricks, the asymmetry disappears. In the case of compounds which are optically active in the liquid state, the twisted structure must be predicated of the molecules themselves, that is, *there must be a twisted arrangement of the atoms which form these molecules.*"

Pasteur, in discussing the molecular constitution of tartaric acids, says that "the molecular structures of the two tartaric acids are asymmetric, and, on the other hand, that they are rigorously the same, with the sole difference of showing asymmetry in opposite senses. Are the atoms of the right acid grouped on the spirals of a right-handed helix, or placed on the solid angles of an irregular tetrahedron, or disposed according to some particular asymmetric grouping or other? We cannot answer these questions. But it cannot be a subject of doubt that there exists an arrangement of the atoms in an asymmetric order having a non-superposable image. It is not less certain that the atoms of the left acid realise precisely the asymmetric grouping which is the inverse of this." Pasteur regarded the formation of asymmetric organic compounds as the special prerogative of the living organism. "Most of the substances of which the animal and vegetable tissues are built up—the proteids, cellulose—are asymmetric organic compounds, displaying optical activity. . . . Mesotartaric acid contains two equal and opposite asymmetric groups of atoms within its molecule." Pasteur was of opinion that compounds exhibiting optical activity were never obtained without the intervention of life. He also says: "Artificial products have no molecular asymmetry; and I could not point out the existence of any more profound distinction between the products formed under the influence of life, and all others." And, again, he refers to the molecular asymmetry of natural organic products as the great characteristic which establishes, perhaps, the only well-marked line of demarcation that can at present be drawn between the chemistry of dead matter and the chemistry of living matter. "Non-living, symmetric forces, therefore, acting on symmetric atoms or molecules, cannot produce asymmetry, since the simultaneous production of two opposite asymmetric halves is equivalent to the production of a symmetric whole, whether the two asymmetric halves be actually united in the same molecule, as in the case of meso-tartaric acid, or whether they exist as separate molecules, as in the left and right constituents of racemic acid. In any case, the symmetry of the whole is proved by its optical inactivity." [1]

SPIRAL ARRANGEMENTS IN THE PHYSICAL UNIVERSE

The spirals which occur in nature are conveniently divided into two great classes—the inorganic and organic—the latter being further divisible into plant and animal spirals.

I have adopted this arrangement because it enables me to classify spirals under three different heads (physical, vegetable, and animal); to compare what may be regarded as dead and living spirals, and to contrast the latter (spirals in plants and animals) with each other. It enables me also to distinguish between the spirals formed by the hard and soft parts of plants and animals, and between non-moving and moving spirals.

All spirals are composed of curves which run into each other by insensible gradations. They are, moreover, characterised by extreme elegance and beauty of form. They present an infinite variety; some being simply twisted upon themselves as a piece of matting might be twisted between the finger and thumb; others being curled up in a flattened spire; others in a conical spire; others in a close coil (flattened or conical); others in an open coil, &c.

Spirals may be right or left-handed; they may be single, in which case they are lop-sided, or unsymmetrical; or they may be double or multiple, when they are symmetrical, carefully balanced structures.

The origin of spirals and spiral movements in the inorganic kingdom is involved in great obscurity. In whirlwinds, in whirlpools, and in nebulæ it is usually attributed to two currents meeting at a certain angle and clashing, with the result that the colliding matter is obliquely deflected and made to assume a spiral course. Such colliding

[1] "Stereo-Chemistry and Vitalism," by Professor F. R. Japp, as given in the "Report of the British Association for the Advancement of Science," 1898.

PLATE CX

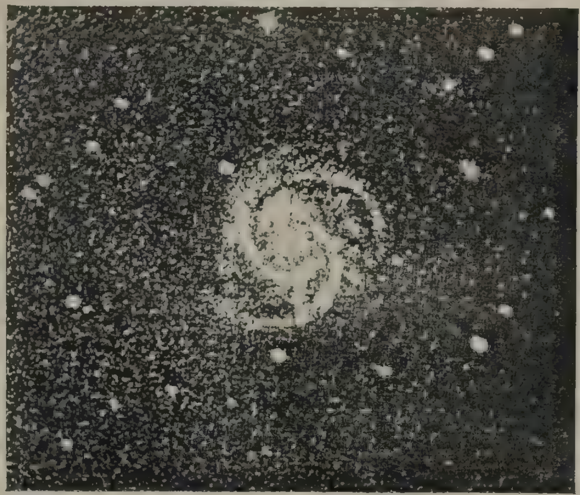


FIG. 1.

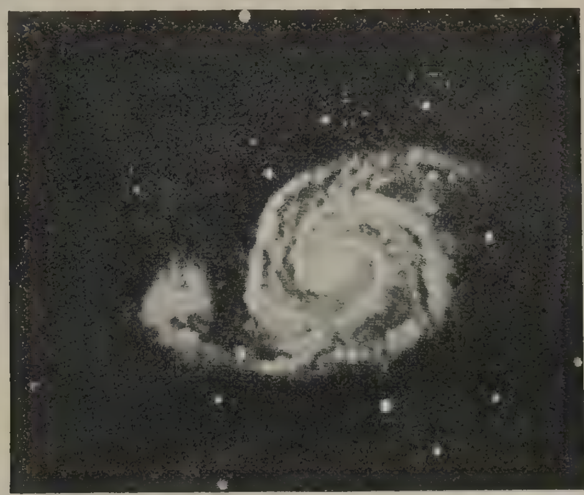


FIG. 2.

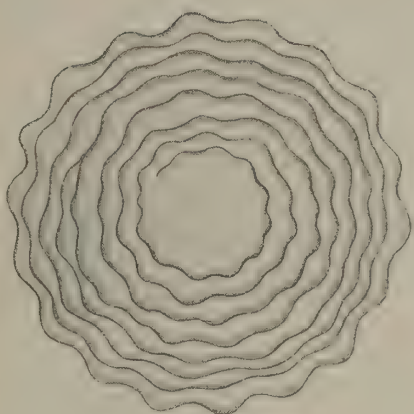


FIG. 3.

FIG. 6.

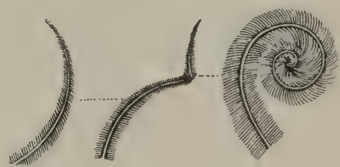


FIG. 5.

FIG. 4.

FIG. 1.—Photograph of Spiral Nebula M. 100, Comæ Berenicis, by Dr. Isaac Roberts, F.R.S. This nebula forms a most exquisite left-handed spiral, with the nucleus very sharply stellar in the midst of faint nebulosity. The convolutions, according to Dr. Roberts, are strikingly perfect, and have several aggregations of nebulosity in them: three or four faint stars are also involved. (Photographs of Stars, Star-clusters, and Nebulæ.)

FIG. 2.—Photograph of Spiral Nebula M. 51, Canum Venaticorum, by Dr. Isaac Roberts, F.R.S. Lord Rosse describes this nebula, and figures it as a strong left-handed spiral structure. According to Dr. Roberts the nucleus of the large nebula consists of a small bright star in the midst of a patch of very dense nebulosity, from which the convolutions radiate in approximately symmetrical forms. The convolutions are broken up into numerous stars and star-like condensations, and there are wisps of nebulosity, with a star involved in each of them. One of these appears to have been deformed, probably by the action of the second nucleus, as indicated by the disarrangement of symmetry. (Photographs of Stars, Star-clusters, and Nebulæ.)

FIG. 3.—Spiral made by the escape of ether in water placed in a red-hot silver basin. In this figure the liquid is seen in plane and the corrugated edges show where the free ether is "rippling" or flowing up from below and through the fluid (Hovenden).

FIG. 4.—Section of a vortex ring made by smoke, in its first stage. The arrows indicate the direction of the motion of the molecules (Hovenden).

FIG. 5.—Remarkable spiral crystals of sulphur obtained by cooling quickly on a microscopic slide. These crystals resemble the fronds of ferns and the horns of animals. A still more remarkable example of a spiral crystal is furnished by prochlorite as shown in Fig. 6.

FIG. 6.—Prochlorite. Shows elegant spiral with transverse markings. (From "System of Mineralogy," by D. T. Dana, 1892.)

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is, however, not necessary. It suffices if matter be allowed to flow into empty spaces, or if it be subjected to varying pressure, or exposed to attractions from nearly, but not quite, opposite points.

The colliding theory of the origin of spiral movements is negatived by the spiral movements occurring in organic matter, such as the fluids and solids of plants and animals.

Thus the movements make their appearance in the reproductive developing cells of certain plants and animals; in the growing stems, leaves, flowers, fruit, and tendrils of climbing plants, in the soft and hard parts of animals, in the organs of locomotion, &c.

SPIRAL ARRANGEMENTS IN THE VEGETABLE KINGDOM

The spirals in the seeds, fruits, leaves, branches, stems, tendrils, and other parts of plants are legion as regards number and variety (Plates cxii. to cxvii.).

They resemble in their general configuration the inorganic spirals and those of animals, so that they form part of the great spiral family which first makes its appearance in the physical universe. They do not differ from the spirals found in nature generally. In climbing plants and such as develop tendrils and other grasping structures they are endowed with a slightly increased degree of sensitiveness which it is only necessary to allude to in passing.

The spiral arrangements in plants have to do with the twisting of the stem on its axis, with circumnutation, with the production of spiral leaves, branches and roots, with the formation of right and left-handed spirals, and with the existence of unsymmetrical and symmetrical spiral structures under whatever circumstances they occur. Wherever curved lines and curved surfaces make their appearance spirality of some kind, as a rule, may be detected, and it is astonishing to what an extent the spiral arrangements prevail.

One has only to examine the plethora of spirals revealed by the vegetable kingdom to be convinced of the accuracy of this observation.

Various examples of spirals (physical, vegetable, and animal) are given in Plates cxi. to cxxvi.

PLATE CXI

Plate cxi. illustrates various kinds of artificial spirals as bearing on spiral formations in plants and animals.

Fig. 1.—A. Left-handed spiral formed by twisting a thin strip of lead in a direction away from the body (see darts).

B. Right-handed spiral formed by twisting the strip of lead towards the body (see darts).

C. An ordinary screw nail forming a right-handed spiral (see darts).

D. A left-handed spiral formed by twining a piece of copper wire round a pencil in the direction indicated by the darts.

E. A right-handed spiral similarly formed.

F. Right and left spirals combined. In this case the spirals overlap or cross at every half turn (see darts). They thus produce a symmetrical whole.

G. Left-handed spiral consisting of two portions starting from opposite points and producing symmetry.

H. Right-handed spiral similarly formed. Drawn by the Author from his experiments.

Fig. 2.—A. Artificial right-handed spiral such as is seen in many plants and animals.

B. Artificial left-handed spiral, the complement of A. The spirals A and B are unsymmetrical or lop-sided.

C. Right and left-handed spirals superposed, the one being placed over the other to produce a symmetrical result. The darts in this figure indicate the right and left-handed spirals referred to. A similar arrangement obtains in plants and animals in a state of nature. Indeed, to produce symmetry two spirals at least are required. Drawn by the Author from his experiments.

Fig. 3.—Cyclostrema, a beautiful example of a flat and of a conical advancing spire. The flat spire is furnished by the operculum, which covers the entrance to the shell and forms a very graceful right-handed spiral, the conical spire being provided by the shell itself, which forms a well-marked left-handed spire.

Fig. 4.—Flat spire of ammonite (*Ammonites bifrons*) forms a left-handed close spire, not unlike the spiral tendrils of the sweet-pea, the spiral embryo of Bunias, the spiral tail of the sloth, and the spiral horns of the ram.

Fig. 5.—A geometrical spiral is here represented. It is defined as a plane curve, not re-entrant, described by a point called the *generatrix*, moving along a straight line according to a mathematical law, while the line is revolving about a fixed point called the *pole* (Webster).

Fig. 6.—The spiral of Archimedes. In this spiral the generatrix moves uniformly along the revolving line, which also moves uniformly.

Figs. 7, 8, and 9.—Hyperbolic, parabolic, and Archimedean spirals are shown.

Fig. 10.—Here is delineated a spiral gear, consisting of a tooth or cog-wheel and a left-handed spiral shaft. When the wheel is made to revolve the spiral shaft is also made to revolve, and the converse. Drawn by the Author from his experiments.

PLATE CXI

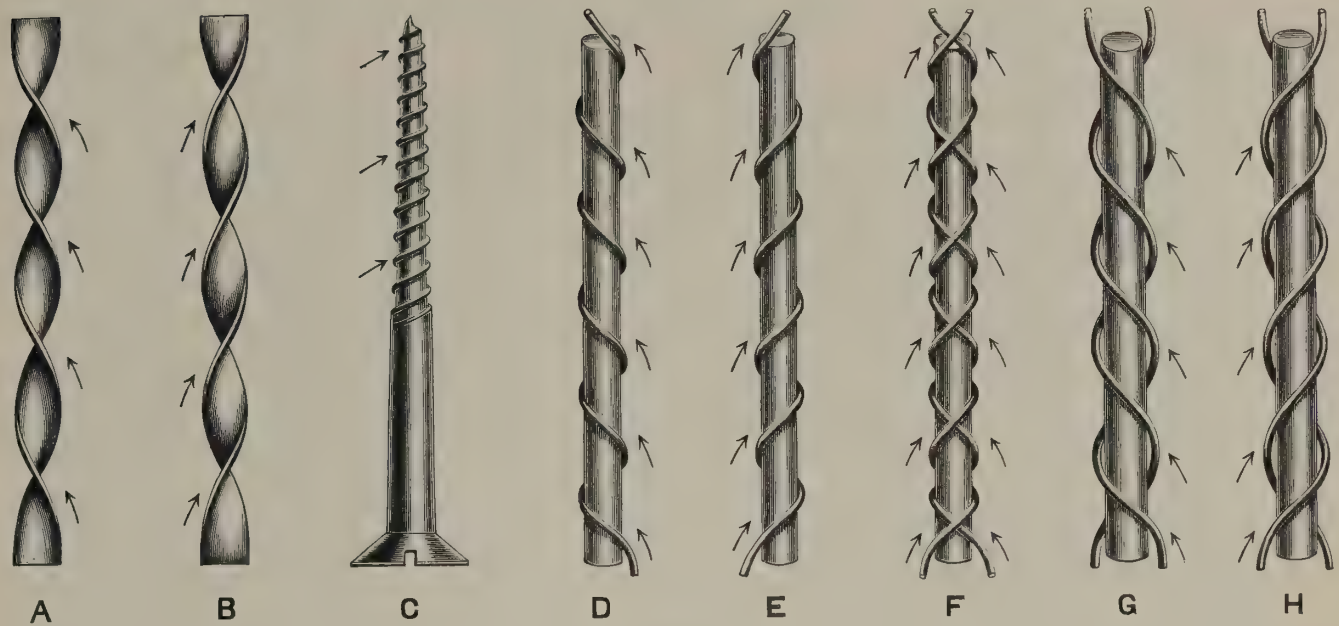


Fig. 1.

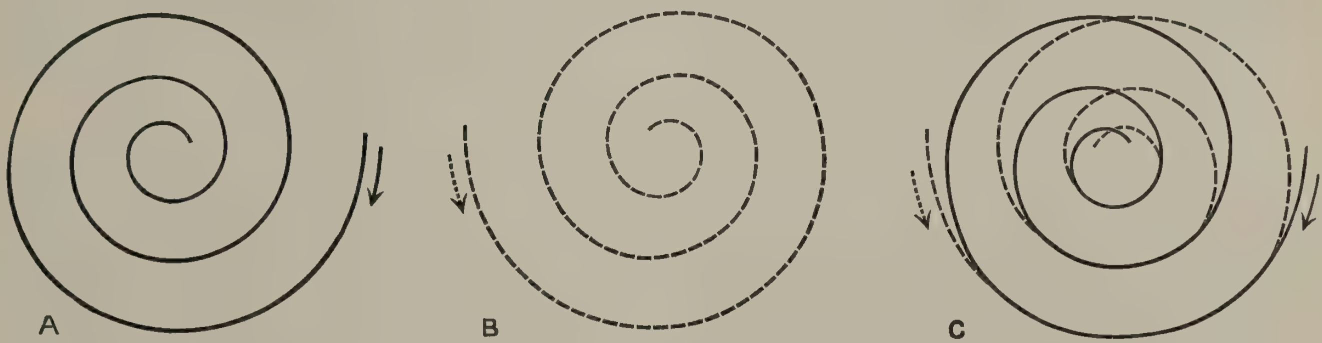


Fig. 2.

Fig. 3.

Fig. 5.

Fig. 6.

Fig. 7.

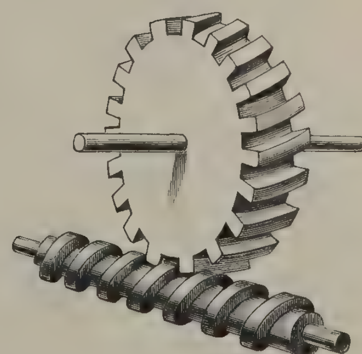


Fig. 4.

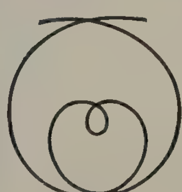


Fig. 8.

Fig. 9.

Fig. 10.

PLATE CXII

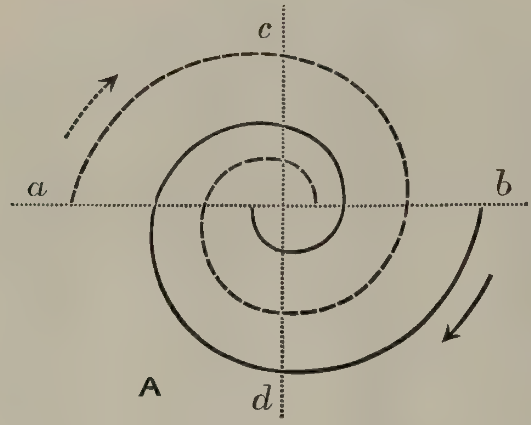


FIG. 1.

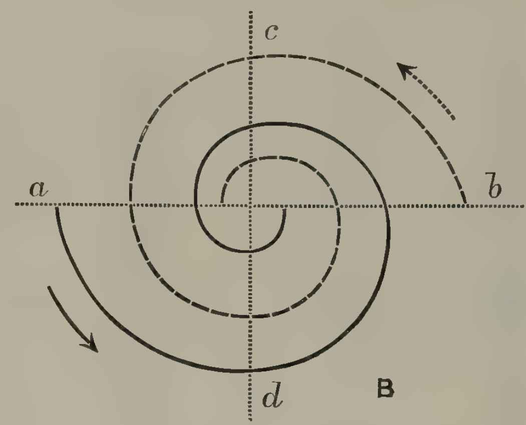


FIG. 2.

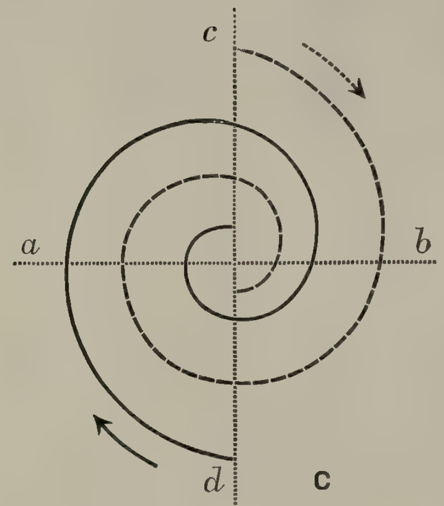


FIG. 3.

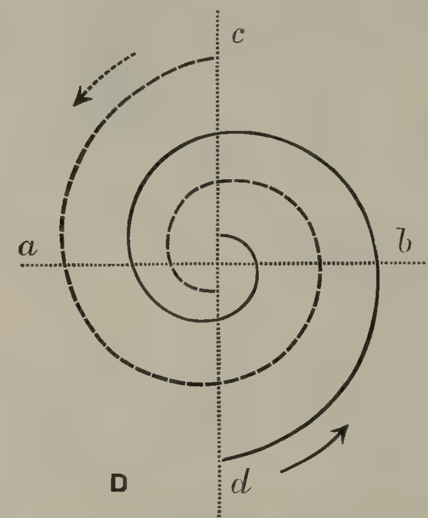


FIG. 4.

FIG. 5.

FIG. 6.

PLATE CXII

Plate cxii.—This plate explains how symmetry is produced in spirals; two spirals at least being required for the purpose.

Fig. 1.—A. Symmetrical right-handed spirals consisting of two parts beginning and terminating at opposite points on a horizontal line (*a*, *b*). The corresponding vertical line is represented at *c*, *d* of Fig. 3.

Fig. 2.—B. Symmetrical left-handed spirals consisting of two parts beginning and terminating at opposite points on a horizontal line (*a*, *b*). The corresponding vertical line is given at *c*, *d* of Fig. 4.

Fig. 3.—C. Symmetrical right-handed spirals beginning and terminating at opposite points of a vertical line (*c*, *d*). The same thing happens in spiral nebulæ as seen at Plate viii., Fig. 4. Similar but opposite spirals occur at Plate viii., Figs. 1, 2, and 3: also at Plate cx., Figs. 1 and 2.

Fig. 4.—D. Symmetrical left-handed spirals beginning and terminating at opposite points on a vertical line (*c*, *d*).

Note.—These spirals (A, B, C, and D) are symmetrical to begin with, but a more perfect symmetry is obtained if the figures are carefully superposed and the horizontal and vertical lines are made to cover each other. Single spirals are lop-sided, two or more being required to produce symmetry. Drawn by the Author from his experiments.

As already explained, examples of bi-lateral spirals composed of two parts are seen in spiral nebulæ (Plate viii., Figs. 1, 2, 3, and 4). Similar spirals are also seen at the apex of the left ventricle of the mammalian heart (Plate lxxxv., Figs. 6 and 8), and in shells at Fig. 7 of the same plate.

Fig. 5.—Species of Medicago. Shows flattened spiral pods (legume). *a*, *a′*, Spiral stem; *b*, *b′*, leaves; *c*, back view of spiral pod; *d*, side view of pod; *e*, front view of pod; *f*, pod opened out, seen from behind and laterally. Here there can be no question as to inherent spiral endowment, as the pods are not, and never have been, in contact with anything but air. Irritability and contact with foreign bodies take no part in the spiral formations. Drawn natural size, by C. Berjeau, from a fresh specimen collected by the Author at Ronda, Spain.

Fig. 6.—Tendrils of vegetable marrow (*Cucurbita Pepo*) coiling and uncoiling. *a*, Tendrils forming right and left-handed close spires; *b*, tendril unwinding or opening; *c*, tendrils opening and making large curves prior to straightening (*f*); *d*, tendril forming close right-handed spire; *e*, tendril opened out; *f*, tendril re-curving and ready to seize a support; *g*, tendril not having caught anything making a left-handed spiral in the air. Drawn from nature, from dissection of a fresh specimen, by C. Berjeau for the Author.

PLATE CXIII

Plate cxiii. illustrates spiral formations in fir cones and palm trees.

Fig. 1.—Cones of *Pinus maritima*, collected by the Author at San Romolo, Italy. The upper left cone (lateral view) shows double spiral arrangement of scales. The upper central cone shows a beautiful right-handed spiral, the upper right cone showing an elegant left-handed spiral. These two cones are weathered and the scales opened out by exposure. The lower left and central cones (basal end views) show the right and left-handed spirals emerging from the axis or stalk of the cone and producing perfect symmetry (compare with D, E of Fig. 11). The lower right cone (apical view) shows the double spiral arrangement in a weathered specimen, where the scales of the cone are opened out or separated. From photographs taken for the Author by his nephew, J. Bell Pettigrew.

Fig. 2.—Date palm growing at San Remo, Italy, photographed for the Author by John A. McMordie. Shows double spiral stem, the right spiral being the more vertical and more pronounced.

Fig. 3.—Date palms growing near that represented at Fig. 2, and photographed for the Author by John A. McMordie at the same time. In the palm to the left, the left spiral is the more vertical and more strongly marked; in the right, the right spiral is the more vertical and more strongly pronounced. Better examples of right and left-handed leading spirals cannot be imagined.

PLATE CXIV

Plate cxiv. shows striking examples of spiral formations in plants.

Fig. 1.—A. Schubertia (*Physianthus*). Stem forming right-handed spiral.
B. *Gloriosa superba*. Leaf terminating in spiral tendril.
C. Croton (*Codiæum*). Leaf forming right-handed spiral.
D. Orchid (*Cypripedium*). Right-handed spiral.
E. Clematis (*C. montana*). Leaf stalks form right and left spirals round alien stems.
F. Convolvulus (*C. arvensis*), forming right-handed spiral round gooseberry twig.
G. Honeysuckle (*Lonicera Periclymenum*), winding from left to right.
H. Two honeysuckle stems entwined and forming left-handed spiral as in the human umbilical cord (Plate xii., Fig. 3) and spiral intestine (Plate xii., Fig. 4). Drawn by C. Berjeau from fresh specimens collected by the Author.

Fig. 2.—Twisted spiral stem or bole of a huge Spanish chestnut (*Castanea vesca*) to be seen in the Island of Inchmahome or Isle of Rest in the Lake of Menteith, Scotland. The stem has evidently been too large to remove, and remains where it was felled. Eighteen inches above the ground it has a circumference of 15 feet, and, at the upper end of the bole, a circumference of 9 feet. I had it specially photographed by a dear friend (I. Maclay) for the present work, and I am fortunate in obtaining a very accurate and spirited rendering of it by C. Berjeau.

PLATE CXIII

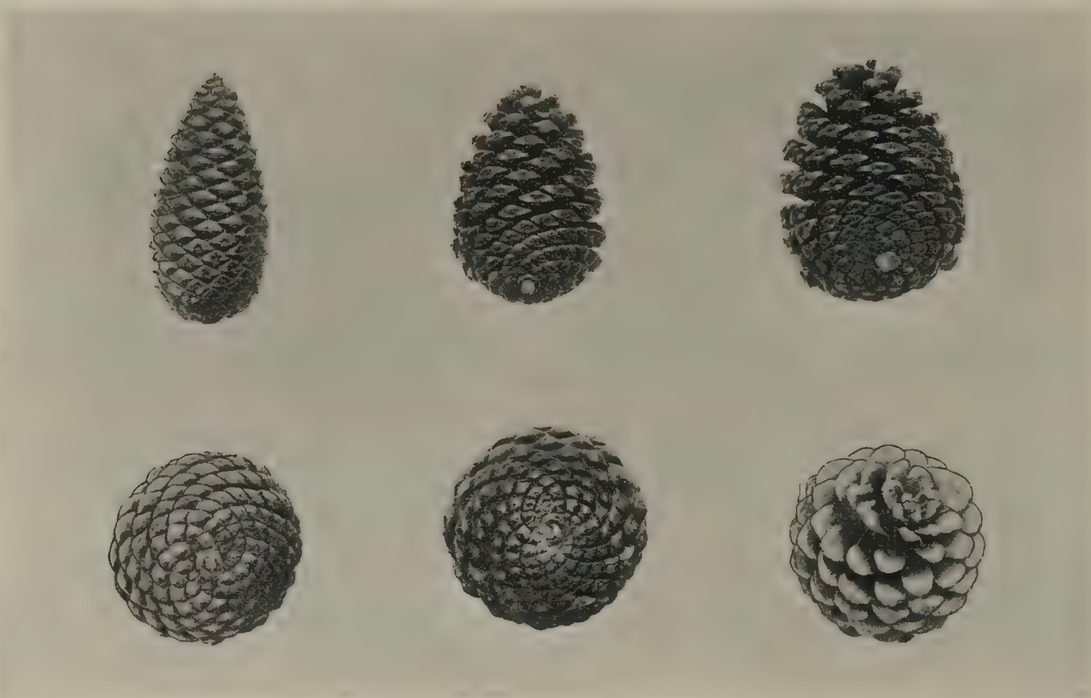


Fig. 1.

Fig. 2.

Fig. 3.

PLATE CXIV

FIG. 1.

FIG. 2.

PLATE CXV

Plate cxv. shows double reversing spirals in the passion-flower and hop: also single spirals in the stem of Tecoma, sweet-pea, and asparagus.

FIG. 1.—Spiral stems and tendrils of the passion-flower (*Passiflora alata*). Shows right and left-handed spirals, double reversing spirals, and spiral tangles.

A. *a*, Stem forming right-handed spiral; *b*, revolving summit of passion-flower with young coiling tendrils; *c*, *c*, *c*, mature tendrils forming single and double reversing spirals.

B. *d*, *e*, Stem of passion-flower twisting from left to right and forming right-handed spiral; *f*, *f*, double reversing spiral and spiral tangle; *g*, *h*, typical example of double reversing spiral tendril.

C. *i*, *j*, Right-handed spiral formed by stem of passion-flower; *k*, *l*, *m*, *n*, *o*, *p*, well-marked examples of double reversing spiral tendrils. The stems and tendrils of the passion-flower are natural spiral formations. The nature and degree of spirality exhibited by them are due to inherent endowment and not to irritability and external stimulation. This follows because the stems and tendrils

PLATE CXV (*continued*)

curve and twist when not in contact with anything save the air. The tendrils even reverse their spirals when similarly circumstanced. Drawn by C. Berjeau from fresh specimens collected by the Author.

Fig. 2.—Specimens of fresh hops sent to the Author from Kent. Drawn by C. Berjeau.

A. Spiral bundle of hop stems. The stems twine into each other and form left-handed spirals.

B. Single hop stem forming a left-handed spiral.

C. Another portion of the same stem forming a right-handed spiral. It is not possible that any form of extraneous stimulation could produce right and left-handed spirals in the same stem. This can only be referred to design and original endowment.

Fig. 3.—A. Spiral stems of Tecoma (*Bignonia*) twisting and forming a right-handed spiral.

B. Sprig of Sweet-pea (*Lathyrus odoratus*) with tendrils forming right and left-handed spirals.

C. Stems of Asparagus (*Asparagus plumosus*) twisting spirally into each other. The twist is in an opposite direction to that figured at A. They form a left-handed spiral. Drawn by C. Berjeau from fresh specimens collected by the Author.

Fig. 4.—A, B. *Chara elastica*, recent. Italy.

A. Sessile oogonia between the divisions of the leaves of the female plant.

B. Magnified transverse sections of a branch, with five oogonia as seen from below (after Lyell).

PLATE CXVI

Plate cxvi.—This plate illustrates the spiral formation in the trunk of a plane tree (*Acer pseudoplatanus*), in the tendrils of the vegetable marrow, in the vessels, seeds, and leaves of plants, in the fronds of a fern, and in specimens of the so-called Devil's corkscrews. The twining of the tendrils of the vegetable marrow is deserving of very special attention, from its twisting on its long axis alternately from right to left and from left to right. Its twining and twisting in opposite directions to form double or right and left-handed spirals is altogether peculiar, and cannot be explained on mechanical principles. The twisting in opposite directions is a natural process, and is not in any way determined by mechanical fixation as is generally believed. The spirals forming the Devil's corkscrew (Fig. 5) receive, it appears to me, a most unlooked-for explanation at D of Fig. 3.

Fig. 1.—Photograph of the spiral stem of a fine old plane tree taken for the present work at Dean's Court, St. Andrews. (Compare with Fig. 2 of Plate cxiv.)

Fig. 2.—Tendrils of vegetable marrow (*Cucurbita Pepo*), showing fine examples of double or reversing compound spirals. These tendrils, in addition to forming double reversing spirals, are twisted on themselves like the stems of many climbing plants.

A. *a*, *b*. Double reversing spiral formed by twisted tendril; *c*, *d*, a similar double reversing spiral. These spirals are growing freely in the air and touching nothing.

B. Striking example of a double reversing compound spiral tendril growing freely in the air and apart from contact, fixation, and stimulation. The spiral is seen reversing at *a*, *b*, *c*, *d*, and *e*. It consists of alternating right and left-handed spirals, and these are obviously the result of growth and original bias, and are, in this sense, inherent or fundamental.

C. Another example of a double reversing spiral tendril. *a*, Left-handed spiral; *b*, spiral reversing to form a right-handed spiral (*c*); *d*, spiral reversing to form a left-handed spiral (*e*); *f*, spiral reversing to form a right-handed spiral. In this case the tip of the tendril has seized a small flower, but the presence of the flower, as explained, is not necessary to the formation of the double spiral. Drawn from nature—fresh specimen—by C. Berjeau for the Author.

Fig. 3.—A. Spiral cell, or cell with a spiral thickening inside, from an orchid.

B. Spiral vessels taken from the melon, showing the elastic walls ruptured and uncoiled.

C. Vertical section of the seed of Bunias, with its spiral embryo. The cotyledons are rolled upon the radicle in a spiral manner, hence the name *spirolobeæ*.

D. Exogenous stem, surrounded by a woody climbing plant (Bush rope), which causes contractions and swellings of the stem. The spiral stem of the Devil's corkscrew, doubtless vegetable in its origin, is obviously produced under similar conditions.

E. A stem with alternate spiral leaves arranged in a quincuncial manner. The sixth leaf is directly above the first, and commences the second spiral cycle (Professor J. Hutton Balfour).

Fig. 4.—A, B, C. Spiral fronds of an actively growing fern. Drawn natural size, by C. Berjeau, from a fresh specimen collected by the Author. Shows right and left-handed spirals.

Fig. 5.—Examples of fossil so-called Devil's corkscrews, dug out of the rock in Nebraska. These remarkable structures are most probably the remains of two aquatic plants, one of which formed a central support or core, the other twining round it like a convolvulus, as represented at Fig. 3 (D). The screws form right and left-handed spirals, and in two of the figures the central supports and the plant winding spirally round them are seen in position. In the other two, the central supports or cores have been removed. The screws are placed vertically, with the exception of a triangular-shaped mass at the bottom of the drawing, which apparently forms the root of one of the climbing plants.

PLATE CXV

Fig. 1.

Fig. 2.

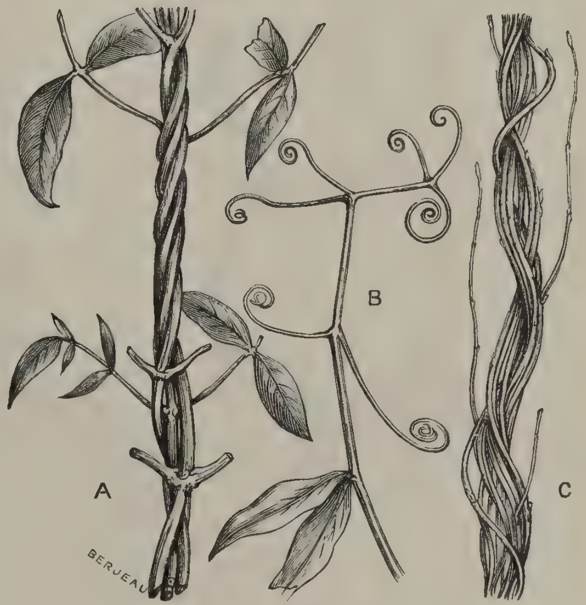


Fig. 3.

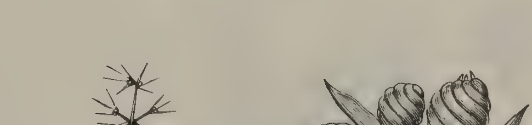


Fig. 4.

PLATE CXVI

Fig. 1.

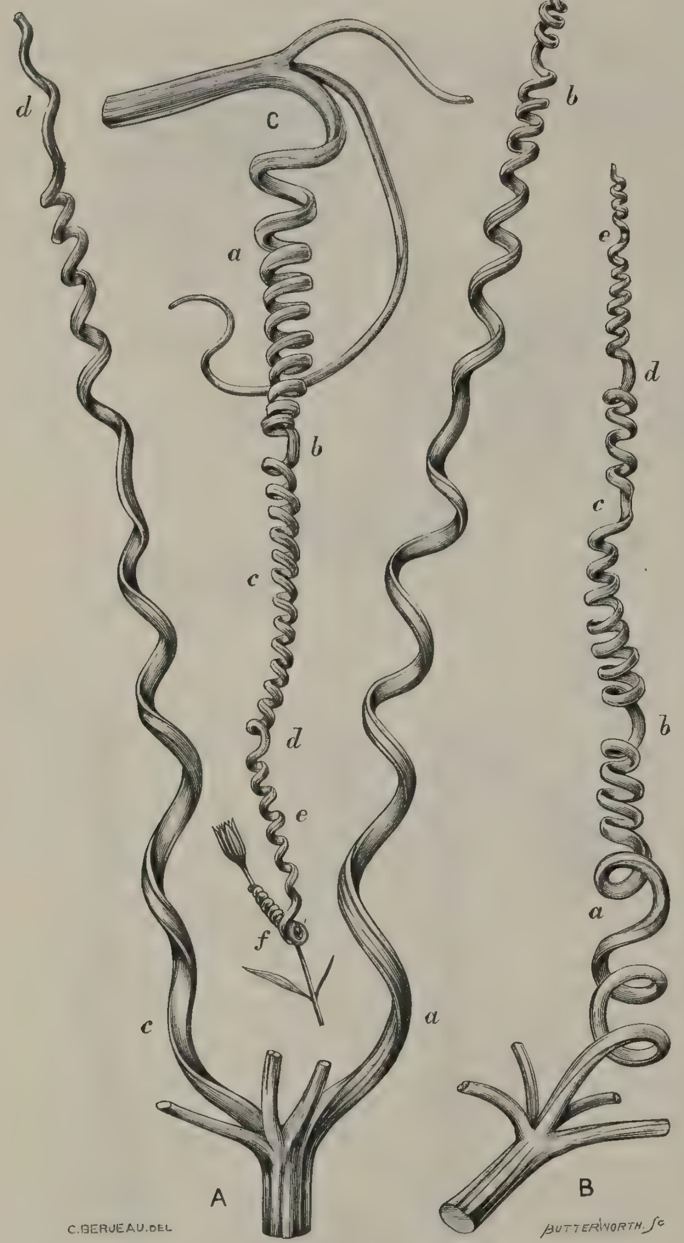


Fig. 2.

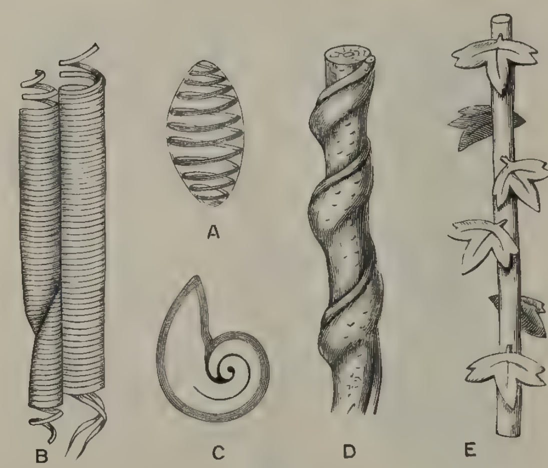


Fig. 3.

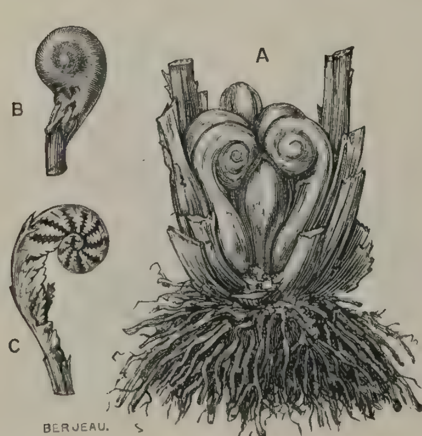


Fig. 4.

Fig. 5.

PLATE CXVII

Plate cxvii. shows simple and complex spirals in great variety. They range from the structure twisted as it were between the finger and thumb, the reversing spiral twisting alternately to right and left, and the highly complex spiral which involutes and evolutes in a very striking and interesting manner. They are all the result of growth, and have nothing whatever to do with irritability, stimulation, and environment. All that can be said of them is that they are living structures, which work out their own destinies independently according to original design and the end for which they were created.

Fig. 1.—The "seeds" of the ash tree flattened and twisted upon themselves after the manner of the screw-propellers in steamships. *a*, *b*, The seeds seen on edge; *c*, the seed seen on the flat; *d*, the seed cut across. Drawn, from a fresh specimen collected by the Author, by C. Berjeau for the present work, full size.

Fig. 2.—Alstrœmeria, displaying radiating whorl of spiral leaves. *a*, Leaf stem; *b*, *c*, *d*, *e*, leaf twisted upon itself, the margins of the leaf being disposed in different planes and revealing double or figure-of-8 curves. Drawn by C. Berjeau from specimen collected by the Author; half natural size.

Fig. 3.—Shoot of climbing plant (*a*, *b*, *c*, *d*) winding spirally round a support (*f*), to form an open advancing coil.

Fig. 4.—Spiral fruit of *Helicteres Isora*. Forms left-handed spiral (after Baillon).

Fig. 5.—A spiral chrysanthemum. Drawn from nature for the present work by C. Berjeau. Displays a left-handed spiral arrangement as seen in spiral nebulæ (Plate viii.); spiral "seeds" (Fig. 6); spiral spermatozoon (Plate xii., Figs. 1 and 2, p. 27); spiral shell (Plate xiii., F, G, p. 28); and the spiral apex of the heart (Plate xvii., Fig. 3, A, p. 32).

Fig. 6.—A. Oogonium of Chara entire, composed of five cells wound round a large central cell in a spiral manner, with corona (*a*).

B. Spiral spermatozoid of Chara separated from a cell. Shows two vibratile cilia (after J. H. Balfour).

C. Fossil carpogonia of Chara. *b*, Side view of *Chara lemani*, ×10; *c*, under view, showing spiral arrangement of cells.

D. *Chara medicaginula*, ×10. *d*, Side view; *e*, under view, showing spiral arrangement of cells.

E. *Chara helicteris*, ×10. *f*, Side view; *g*, under view; and *h*, top view, showing spiral arrangement of cells; *i*, one of the spiral cells detached (after Cuvier).

The spirals shown at D and E of this figure resemble the spirals seen in nebulæ (Plate viii., p. 17), certain shells (Plate xiii., F and G, p. 28), certain cones (Plate xi., Fig. 1, p. 25), and the apex of the heart (Plate xvii., Fig. 3, A, p. 32).

Fig. 7.—Terminal stem and shoot of vegetable marrow with tendrils in various stages of development, and forming single right and left-handed spirals, and one double or reversing spiral.

A. *a*, *b*, *c*, Three sets of young tendrils closely coiled up and forming right and left-handed spirals; *d*, peduncle bearing five tendrils in various stages of development; *e*, very young tendril closely coiled and forming a left-handed spiral; *f*, young tendrils uncoiling and forming a right-handed spiral; *g*, young tendril uncoiling and forming a right-handed spiral; *h*, young tendril uncoiled and beginning to reverse its spiral; *i*, mature tendril re-coiling and forming a left-handed spiral. The tendrils *e*, *f*, *g*, *h*, *i* have not touched or caught hold of anything, and are therefore natural spiral formations.

B. Stem, *a*, of vegetable marrow with three tendrils; *b*, mature tendril growing freely in space which has coiled upon itself to form a single pyramidal-shaped left-handed spiral.

C. Stem, *a*, of vegetable marrow having three tendrils, *b*, *c*, *d*; *b*, young tendril which has uncoiled and straightened itself; *c*, mature tendril in the act of re-coiling and forming a left-handed spiral; *d*, *e*, *f*, mature tendril which has re-coiled and forms a double or reversing spiral: at *d*, the spiral is left-handed; at *e*, the spiral is reversing, and at *f*, it is right-handed. The power possessed by plants of forming right and left-handed and double or reversing spirals is a feature of extraordinary interest, as proving original endowment. In Fig. C, as in Figs. A and B, the tendrils are growing freely in space: the single right and left-handed and double reversing spirals are therefore natural formations, and are not due to inherent irritability or stimulation caused by coming in contact with anything living or dead. Similar remarks are to be made of animal tissues: muscles, nerves, bones, horns, claws, teeth, shells, &c., all assume spiral forms quite apart from either irritation or stimulation.

Drawn three-fourths natural size, by C. Berjeau, from fresh specimens collected by the Author.

Fig. 8.—A. "Transverse section of a revolute leaf. The two edges are rolled outwards or away from the axis.

B. "Transverse section of an involute leaf. The two edges are rolled inwards or towards the axis.

C. "Transverse section of a convolute leaf. The leaf is rolled upon itself so as to form a continuous coil.

D. "Transverse section of a plicate or plaited leaf. The parts of the leaf are folded together like a fan.

E. "Circinate vernation, in which the leaf is rolled up from apex to base, like a crosier.

F. "Diagram to illustrate contorted or twisted æstivation, in which the parts of the whorl are overlapped by each other in turn, and are twisted on their axes as in the mallows.

G. "Diagram of the flower of the Sowbread (*Cyclamen*), showing the five sepals overlapping each other, and five petals arranged in a contortive manner, five stamens, and the pistil in the centre" (Professor J. Hutton Balfour).

SPIRAL ARRANGEMENTS IN THE ANIMAL KINGDOM

The spiral arrangements in animals are, if possible, more remarkable than those witnessed in plants. In animals the softest and even the hardest tissues assume the spiral form. The spermatozoa, the ova, the muscles, nerves, feathers, shells, horns, bones, and teeth all attest the prevalence of the spiral as a factor in organisation.

PLATE CXVII

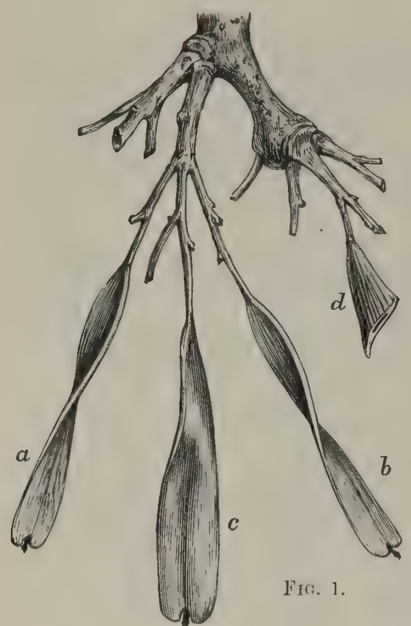


Fig. 1.

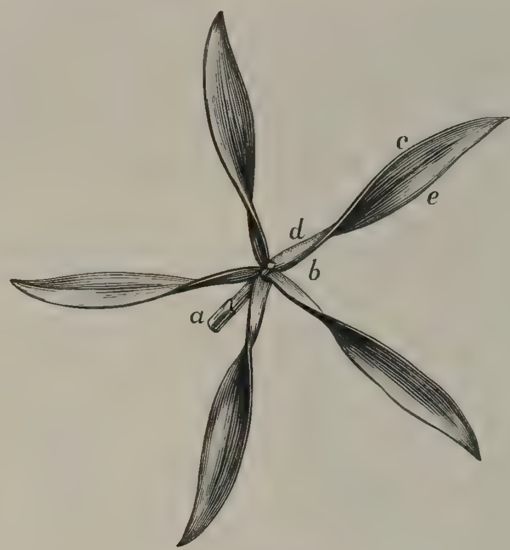


Fig. 2.

Fig. 3.

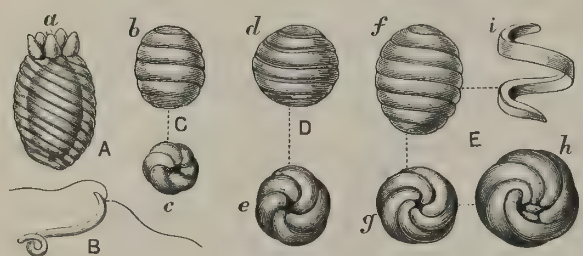


Fig. 6.

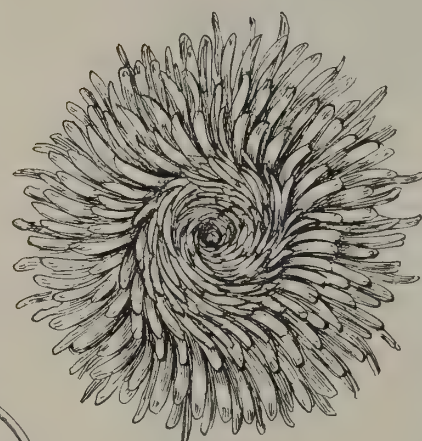


Fig. 5.

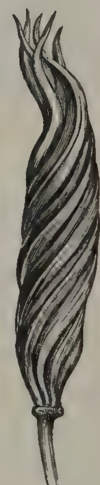


Fig. 4.

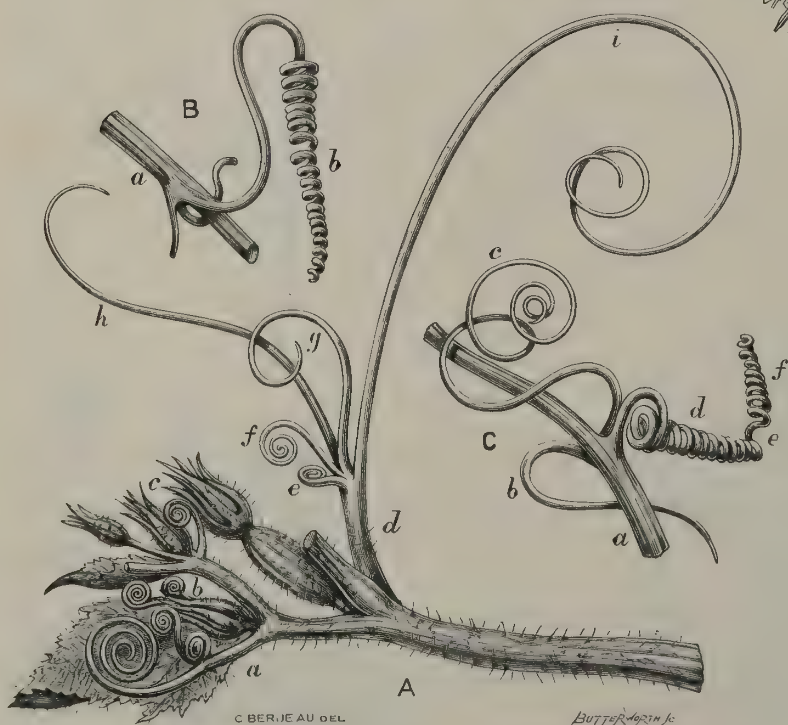


Fig. 7.

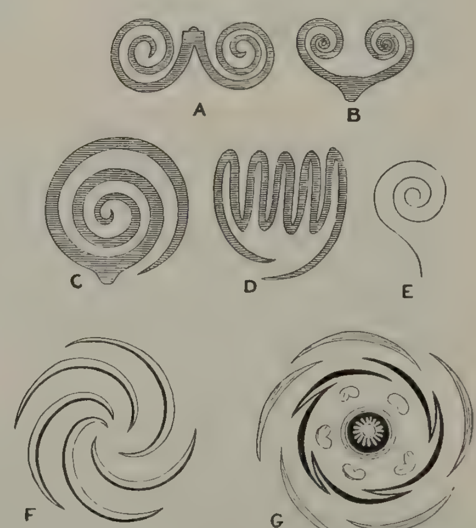


Fig. 8.

Nothing short of design and pre-arrangement and fundamental bias can account for the occurrence of spiral arrangements in such a great variety of substances. The presence of spirals in great numbers in plants where there is comparatively little differentiation would have been sufficiently striking, but when we find them in great abundance in the tissues of all animals, even the highest and most complex, we are forced to look for a cause, and to remove them from the category of chance formations. We are obliged to fall back upon Design and Law and Order. The necessity for this procedure becomes imperative when it is remembered that spiral arrangements are not confined to plants and animals, but are also found in molecules, crystals, nebulæ, cyclones, sand-storms, water-spouts, whirlpools, &c.

The spiral formations in animals are not only outstanding and typical but they are bewildering as regards variety and detail. It would be easy to adduce any number in corroboration, but it will suffice for the present if I give sufficient to illustrate the general principle, which I do in the following nine plates (Plates cxviii. to cxxvi. inclusive). Further illustrations of an important kind will be found in the body of the work.

PLATE CXVIII

Plate cxviii. illustrates spiral formations and structures in spermatozoids, umbilical cord, intestine, and nerve cells.

Fig. 1. Spiral spermatozoon of Crayfish (*Astacus fluviatilis*) (after Huxley), × 850.

A, B, C, D. Different stages in the development of a spermatozoon from a seminal cell.

E. A mature spermatozoon—front view. The mature spermatozoon (E) consists of a right and left set of radiating spiral elements seen in the uncoiled state at C. The spermatozoon is bi-laterally symmetrical, and bears a remarkable resemblance to the two sets of spiral nebulæ seen at Plate cx., to the two spiral shells seen at Plate xiii., Fig. 1, D, E; and to the spiral apex of the heart, seen at Plate xvii., Fig. 3, A. The spermatozoon is an embodiment of evolving spiral force (the Author).

Fig. 2. Spiral spermatozoa of various kinds.

A. Spermatozoon of Triton (*Triton cristatus*), × 450.

B. Spermatozoa of rabbit (*Lepus cuniculus*), × 450.

C. Spermatozoon of field mouse (*Arvicola arvalis*), × 450.

D. Spermatozoon of wood shrike (*Lanius rufus*), × 450.

E. Spermatozoon of goldfinch (*Fringilla elegans*), × 450.

F. Spermatozoon of perch (*Perca fluviatilis*), × 450.

G. Spermatozoon of blackbird (*Turdus merula*), × 450.

H. Spermatozoon of man (*Homo sapiens*), × 450.

I. Spermatozoon of frog (*Rana temporaria*), × 450.

J. Spermatozoon of rat (*Mus rattus*), × 450.

K. Spermatic cyst of common creeper bird (*Certhia familiaris*), containing a bundle of spermatozoa, × 500.

L. Spermatic cyst of rabbit. *a*, The globules, each of which contains a spermatozoon, × 350; *b*, separate globuli, × 500 (after Griffith and Henfrey).

Fig. 3.—Human umbilical cord, composed of one vein (*a*) and two arteries (*b*), intertwining to form a symmetrical left-handed spiral. Resembles spiral water-spout (Plate vi.), and the twining stems of the hop (Plate x., Fig. 2, A). Two spirals at least are necessary to produce symmetry, structures composed of one spiral being incomplete or lop-sided. Drawn from injected specimen in the possession of the Author by C. Berjeau.

Fig. 4.—*Sipunculus nudus* laid open from the side, showing left-handed spiral intestine (*a*); *b*, anus (after W. Keferstein). Resembles spiral umbilical cord (Fig. 3 of this plate), and spiral hop stems (Plate x., Fig. 2, A, B).

Fig. 5.—A. Ganglion cell of a frog, with right-handed spiral nerve fibres, magnified. *a*, *a*, Straight fibre; *b*, large coiling fibre; *c*, small coiling fibre (after Lionel S. Beale). Resembles twining plants (Plate x., Fig. 3, A).

B. Ganglion cell from the sympathetic system of the frog, with left-handed spiral nerve fibre magnified. *a*, Straight fibre; *b*, coiling fibre, arising by a superficial netting connected with the nucleolus of the cell; *c*, *c*, capsule with nuclei (after J. Arnold). Resembles twining plants (Plate ix., Fig. 3, A and F).

PLATE CXIX

Plate cxix. illustrates spiral formations in shells.

Fig. 1.—Spiral Foraminifera after Brady. *Challenger* Reports, vol. ix. In estimating the direction of the spirals in these shells the spirals are traced from without inwards, or from base to apex (the Author).

A. *Discorbina eximia*, × 35.
B. *Discorbina biconcava*, × 45. } Chambord right-handed spiral shells.

C. *Calcarina defrancii*, × 20. Spiculated left-handed spiral shell.

D. *Cristellaria calcar*, × 35. Curious plicated left-handed spiral shell.

E. *Orbiculina adunca*, × 20. Symmetrical shell with left-handed spiral whorl at apex. Resembles spiral nebulæ (Plates vii. and viii.), certain spiral cones (Plate xi., Fig. 1, lower row), and spiral cast of heart (Plate xvii., Fig. 3, B).

PLATE CXVIII

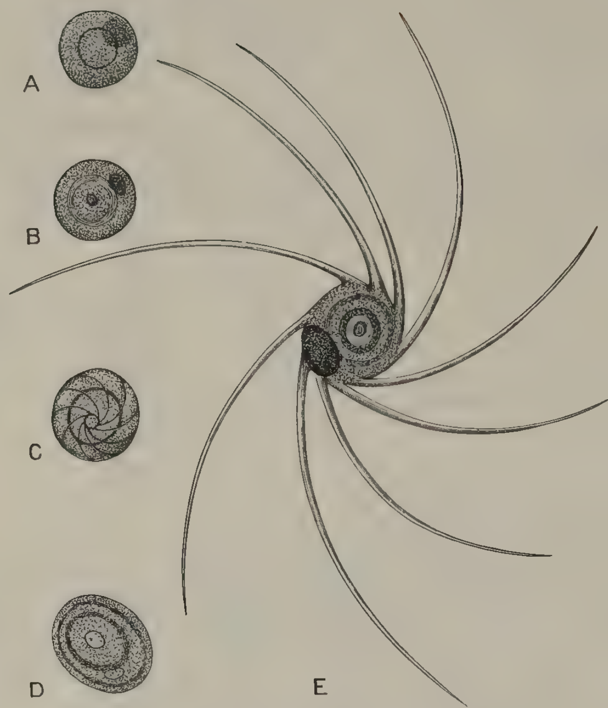


Fig. 1.

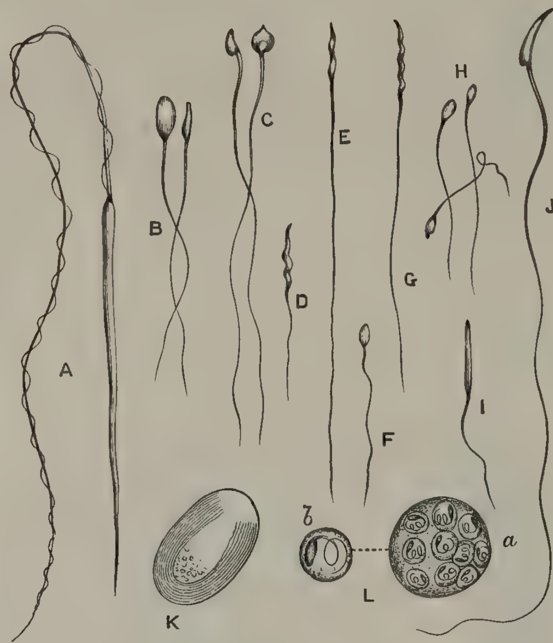


Fig. 2.

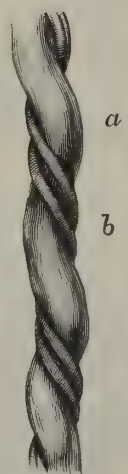


Fig. 3.

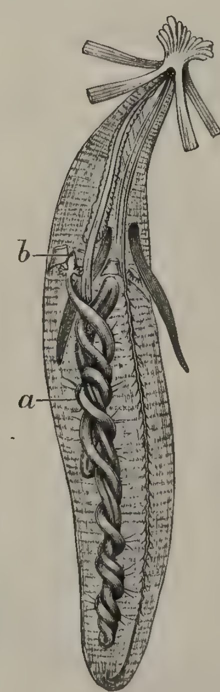


Fig. 4.

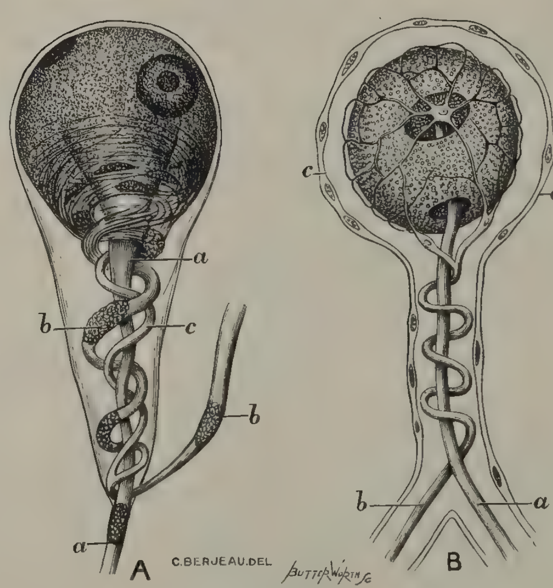


Fig. 5.

PLATE CXIX

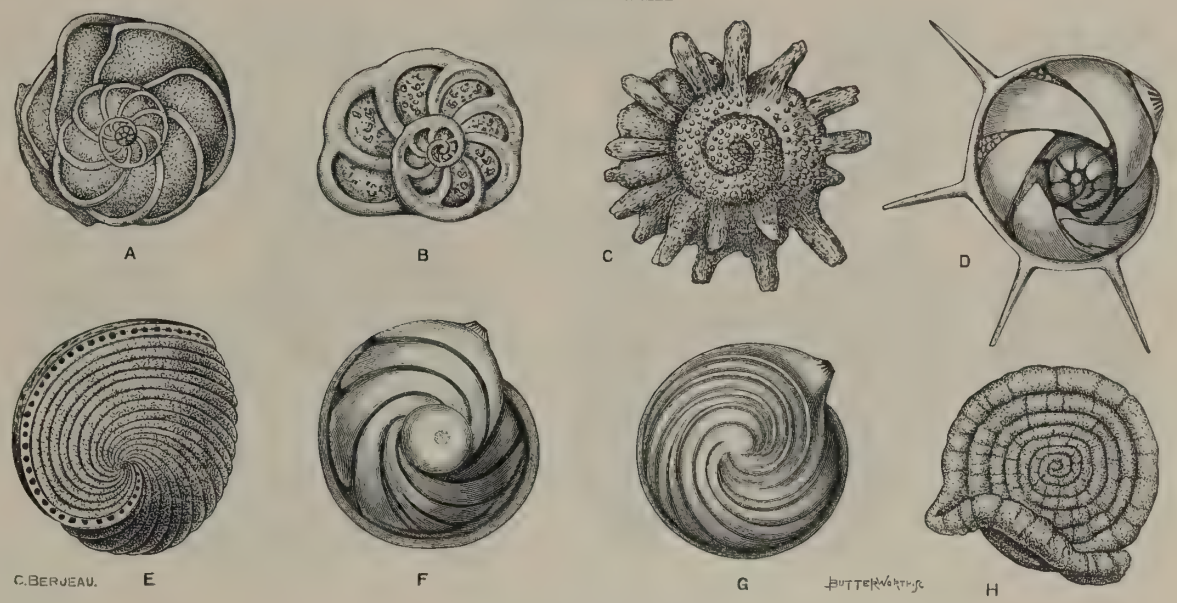


PLATE CXIX (*continued*)

F. *Cristellaria orbicularis*, ×20.

G. *Cristellaria vortex*, ×20. F and G are symmetrical shells with right-handed spiral whorls at apex. They resemble nebulæ (Plate viii.); spiral "seeds" (Plate cxvii., Fig. 6, D, E); spiral spermatozoon (Plate cxviii., Fig. 1, E); and the spiral apex of the heart (Plate xvii., Fig. 3, A).

H. *Ammodiscus tenuis*, ×12. Crenated right-handed spiral shell with many and fine convolutions.

PLATE CXX

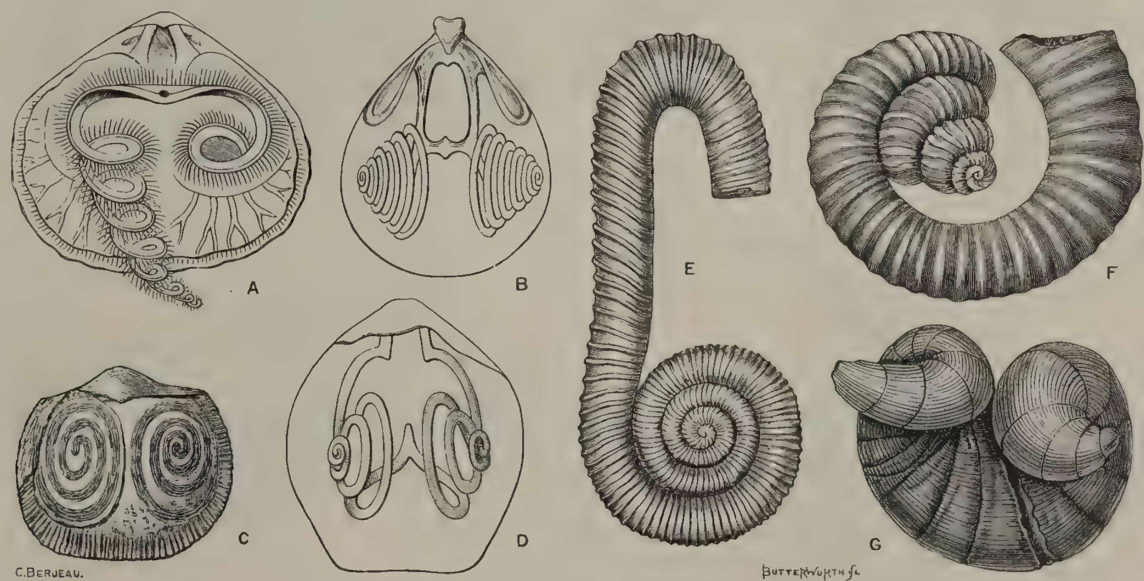


Plate cxx. illustrates spiral configuration of shells.

FIG. 1.—A. *Rhynchonella psittacea*. Shows interior of dorsal valve. The spiral labial appendage at the right of the figure is coiled and occupies its normal position: the spiral labial appendage at the left side is uncoiled and displaced (after Davidson).

B. Restored interior of dorsal valve of *Uncites gryphus* from the Middle Devonian, showing beautiful right and left-handed spirals (after Davidson).

C. *Koninckina leonhardi* from the Trias of St. Cassian, enlarged. Displays right and left-handed brachial processes (after Zittel).

D. Interior of the dorsal valve of *Dayia navicula*, Silurian, enlarged (after Davidson). Repeats the right and left-handed spiral arrangements seen in A, B, and C.

E. *Macroscaphites ivanii*. Cretaceous (Neocomian).

F. *Heteroceras emerici*. Cretaceous.

G. *Diceras arietina*. Upper Jurassic.

Figs. E, F, and G display unusual spiral forms, E forming a left and F a right-handed spiral, and G a right and left-handed spiral united. The number and variety of spirals in shells is incredibly great.

PLATE CXXI

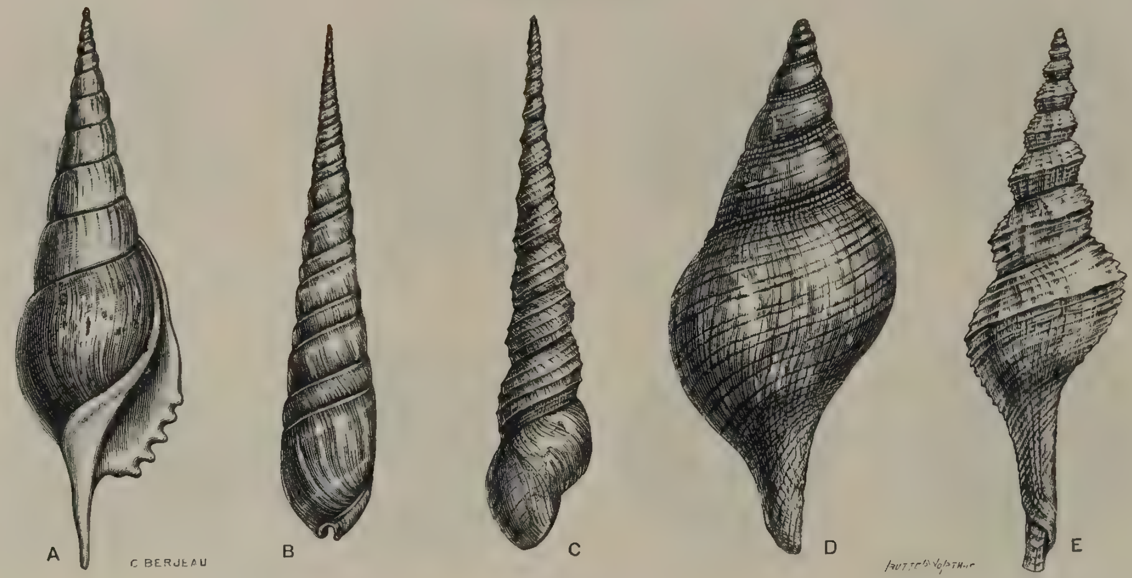


Fig. 1

Fig. 2.

Plate cxxi. illustrates spiral formations in shells and horns.

Fig. 1.—Shows typical pyramidal-shaped, right-handed shells which bear a marked resemblance to many horns.

A. *Rostellaria curvirostris.*
B. *Terebra dimidiata.*
C. *Turritella* (sp.).
D. *Fasciolaria tulipa.*
E. *Fusus dupetit-thouarsii.*

Drawn by C. Berjeau from photographs by the Author.

Fig. 2.—Shows typical right and left-handed spiral horns. These horns, especially those figured at F, bear a striking resemblance to the spiral shells (Fig. 1 of this plate).

A. Head and spiral horns of West African harnessed antelope (*Tragelaphus gratus*).
B. Head and spiral horns of the Addax antelope (*Addax nasomaculatus*).
C. Head and spiral horns of Grant's gazelle (*Gazelli granti*).
D. Head and spiral horns of the black buck (*Antilope cervicapra*).
E. Head and spiral horns of the Angora goat (*Capra hircus*).
F. Head and spiral horns of the Markhor goat (*Capra falconeri*).

Drawn by C. Berjeau for the Author.

PLATE CXXII

Plate cxxii. illustrates spiral shell formations and their resemblance to similar spiral formations in the bony portions of the inner ear (human).

Fig. 1.—Examples of various shells forming elegant right and left-handed close and open spirals.

A. *Euomphalus pentangulatus* (Woodward). Forms left-handed, close, flat spiral.
B. *Crioceras emerici.* Forms left-handed, open, flat spiral.
C. *Ecculiomphalus distans.* Forms right-handed, open, flat spiral.
D. *Siliquaria anguina.* Forms left-handed, semi-open, conical spiral.
E. Phragmacone of *Spirula fragilis.* Forms left-handed, open, flat spiral.

PLATE CXXII

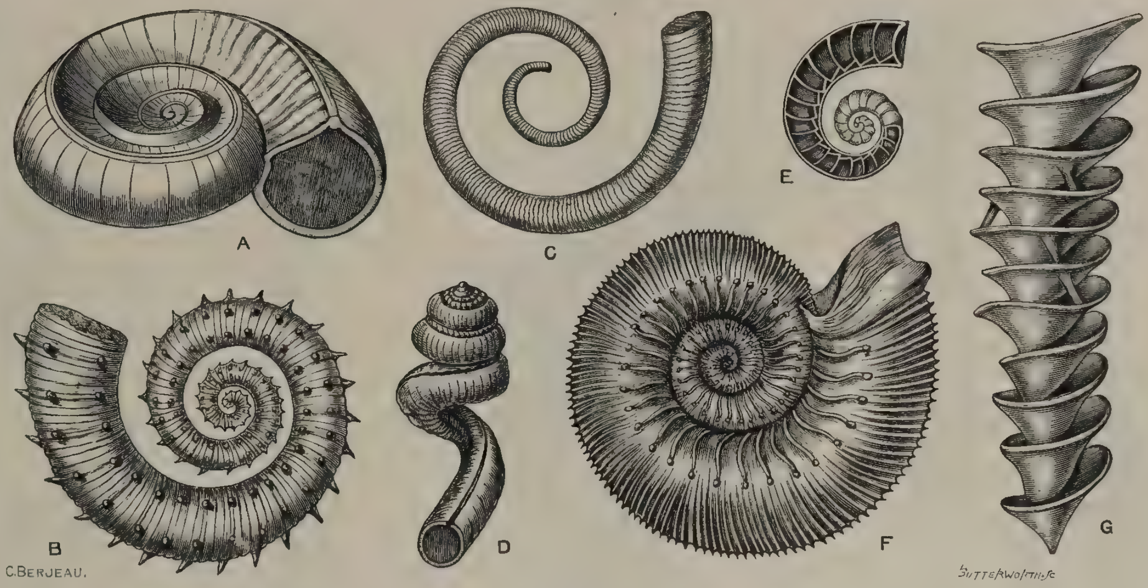


FIG. 1.

FIG. 2.

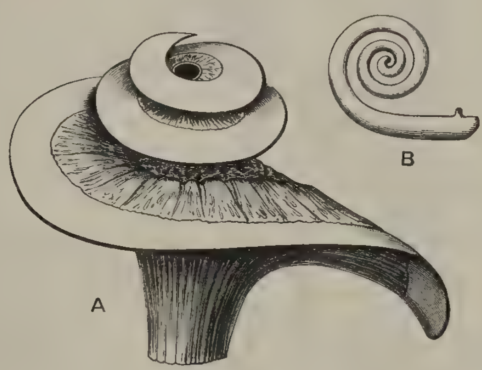


FIG. 3.

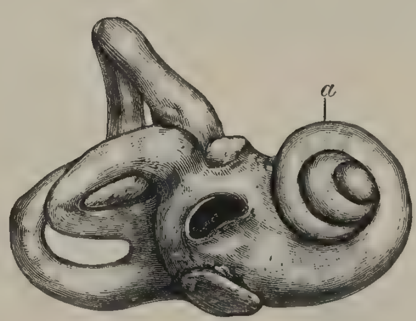


FIG. 4.

PLATE CXXII (*continued*)

F. *Stephanoceras (Ammonites) humphresianum.* Forms right-handed, close, flat spiral.
G. Axis of *Archimedes wortheni.* Forms left-handed, elongated, close spiral. From Nicholson's and Lydekker's "Palæontology."

FIG. 2.—Remarkable examples of right and left-handed spirals occurring in the inner portion of the human ear.
A. Cochlea of ear laid open. *a, a′*, Osseous wall; *b, b′*, *lamina spiralis*; *c*, strands of cochlear nerve folding over at *d, d′*.
B. Osseous labyrinth of left internal ear seen from without. *a*, Cochlea; *b*, semicircular canals (after Hirschfeld and Leveillé).

FIG. 3.—A. Laminæ of cochlea of internal ear exposed (after Rüdinger).

FIG. 4.—Bony labyrinth of right internal ear of child. *a*, Cochlea. The semicircular canals are seen at the left of the figure (after Rüdinger).

PLATE CXXIII

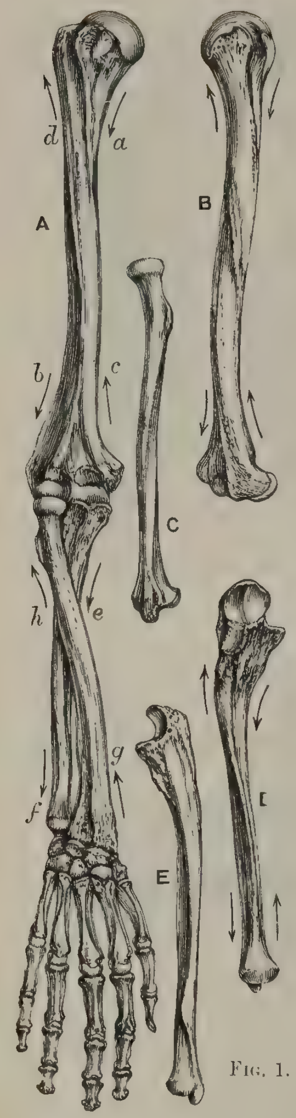


FIG. 1.

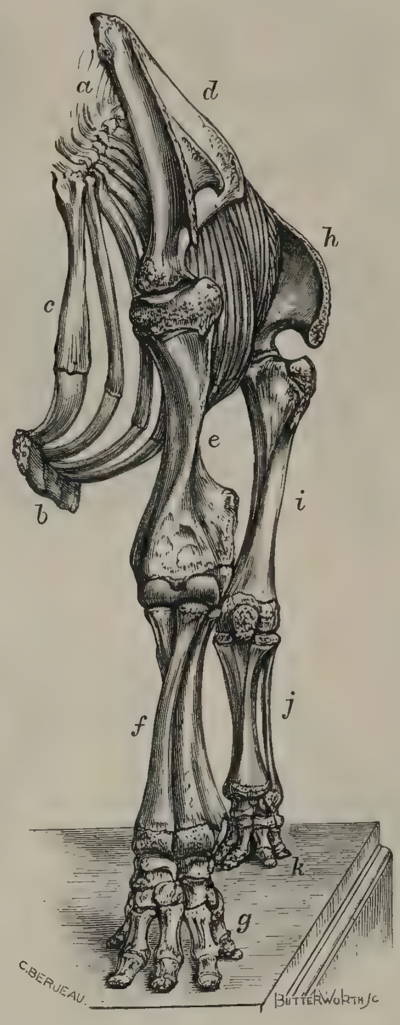


FIG. 2.

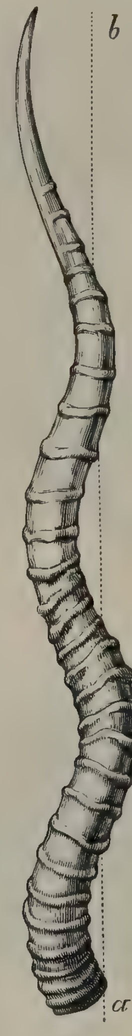


FIG. 3.

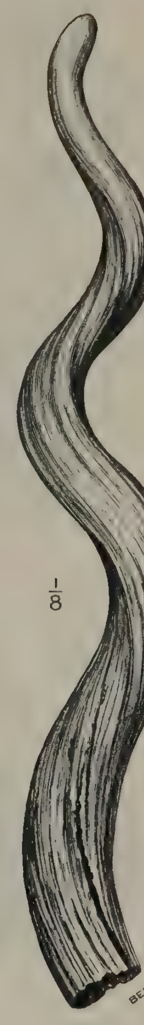


FIG 4.

FIG. 6.

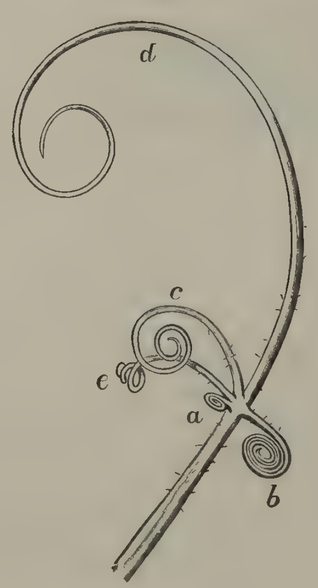


FIG. 7.

FIG. 5.

PLATE CXXIII

Plate cxxiii. illustrates the spiral formation of human bones as seen in the arm, leg, vertebral column, clavicle, scapula, and pelvis.

Fig. 1.—Bones of right upper extremity of man with the hand pronated: also separate bones. All these bones present fine examples of spiral structures; pronation of the hand being performed by the radius twisting round the ulna.

A. The spirality or twist in the humerus or arm bone is indicated by the darts *a*, *b* and *c*, *d*, and in the radius and ulna by the darts *e*, *f* and *g*, *h*.

B. Another view of the humerus; the darts, as before, indicating the nature and the degree of spirality.

C. Radius (one of the bones of the forearm) twisted upon itself.

D. Ulna twisted upon itself (see darts).

E. Different view of ulna. The bones of the lower extremity (femur, tibia, and fibula) are also twisted, and so resemble the bones of the upper extremity.

Drawn to scale by C. Berjeau from specimens in the Author's museum.

Fig. 2.—Portion of the skeleton of an Indian elephant (*Elephas indicus*) in the Museum of the Royal College of Surgeons of England. Shows marked spirality in the bones of the left fore and left hind limbs.

A. Vertebral column; *b*, sternum; *c*, ribs; *d*, scapula; *e*, humerus; *f*, radius and ulna; *g*, bones of foot; *h*, pelvis; *i*, femur; *j*, tibia and fibula; *k*, bones of foot. The bones of the limbs are not only twisted upon themselves, but, in the case of the radius and ulna, and the tibia and fibula, they twist round each other. The spirality resembles that seen in the bones of the extremities of man (Fig. 1); the wing of the bird (Plate xlvii., Fig. 1); the cast of the left ventricle of the heart (Plate xvii., Fig. 3, A); and certain trees (Plate cxiii., Figs. 2 and 3; Plate cxvi., Fig. 1); fruit (Plate xxiii., Fig. 1), and horns (Plate xv., Fig. 2, D, E).

Drawn by C. Berjeau from photograph specially taken for the Author.

Fig. 3.—Spiral annulated horn of the Addax (*Addax nasomaculatus*). The line *a*, *b* shows the amount of spirality.

Fig. 4.—Example of curious spiral tusk of an elephant in the Royal College of Surgeons of England, carefully drawn, from actual measurements of the specimen, by C. Berjeau for the present work. The tusk presents the general appearance of a spiral horn as seen in many antelopes (compare with Figs. 3 and 5). It is peculiar in this respect, that it twists upon its axis in the direction of its length, and makes a series of open curves similar to those seen in many climbing plants and tendrils.

Fig. 5.—Horn of the koodoo (*Strepsiceros Kudu*) forming an exquisite open left-handed spiral. The imaginary axis (*a*, *b*) has been introduced to show how a foreign substance may be inserted within the spiral coils. Drawn by C. Berjeau for the Author from the tusk itself.

Fig. 6.—Abnormally curved tusk of an elephant, to be seen in the Hunterian Museum of the Royal College of Surgeons of England. The tusk forms a beautiful open spiral which resembles that in the tusk of the mammoth, the tendrils of the vegetable marrow (Fig. 7), and other climbing plants. Specially drawn for the present work by C. Berjeau.

Fig. 7.—Tendrils of vegetable marrow displaying varying degrees of spirality. They also show how the tendrils form flat and conical spires. They further show how the small spires as they grow open out to form large spires and spirals resembling the tusk of the elephant seen at Fig. 6. *a*, Rudimentary or young spire; *b*, fully formed, closely coiled flat spire; *c*, flat spire uncoiling and preparing to seize supports in its vicinity; *d*, spire, further uncoiled and forming a large open coil resembling some elephants' tusks, the teeth of the *Barbirusa alfurus*, the abnormal incisor teeth of rabbits and other animals, the curved spiral tail feathers of Wilson's bird of paradise (*Diphyllodes wilsoni*); *e*, tendril partly opened out and forming a conical spire, &c. (see Figs. 3, 4, and 5 of Plate cxxiv.). Drawn by C. Berjeau from a fresh specimen collected by the Author.

PLATE CXXIV

Plate cxxiv.—This plate shows a great variety of spirals, in feathers, shells, horns, teeth, &c. It displays the straight spiral where the structure in which it occurs is simply twisted upon itself, as in the narwhal; the tusks of the mammoth and elephant making large open spirals; the double spiral made by the columella and outer portion of the shell of the *Mitra episcopalis*; the beautiful spirals formed by the tail feathers of the bird of paradise; the very striking spirals made by the horns of the koodoo, and Pamir sheep; and the exquisite spiral fringe characteristic of the corkscrew sea-fan.

Fig. 1.—A. Spiral tusk of the narwhal (*Monodon monoceros*) twisted in the direction of its length. The tusk forms a left-handed spiral composed of several strands, and producing a symmetrical combination. The tusk is waved and shows a tendency to coil round a central support. This is one of the largest examples of a spiral tooth.

B. Portion of the same tusk on a larger scale.

Fig. 2.—A. Head and spiral tusks of the mammoth (*Elephas primigenius*) (after Tilsens). The great tusks of the mammoth furnish striking examples of spiral formations in the animal kingdom.

B. Head, tusks, and spiral trunk of the African elephant (*Elephas africanus*). The trunk of the elephant supplies an example of a soft, yielding, temporary spiral, similar to that seen in the tail of the spider monkey, the two-toed ant-eater, Merian's opossum, and the tendrils of certain climbing plants; the tusks of the mammoth and elephant supplying examples of permanent spirals seen also in teeth, horns, bones, &c. Drawn by C. Berjeau for the Author.

Fig. 3.—View of a spiral shell (*Mitra episcopalis*) sawn through longitudinally, showing columella with right-handed spiral folds (after Zittel). This affords the type and plan for many spiral staircases.

PLATE CXXIV

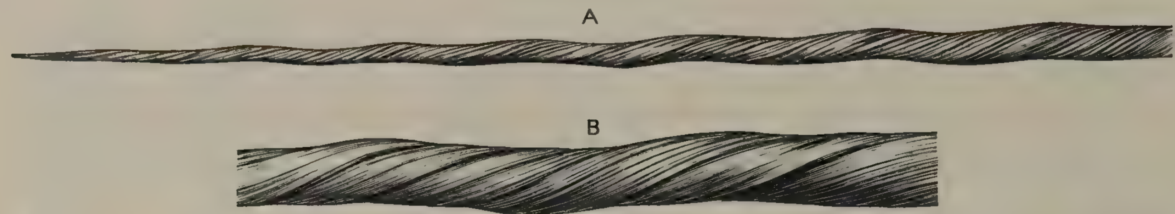


Fig. 1.

Fig. 3.

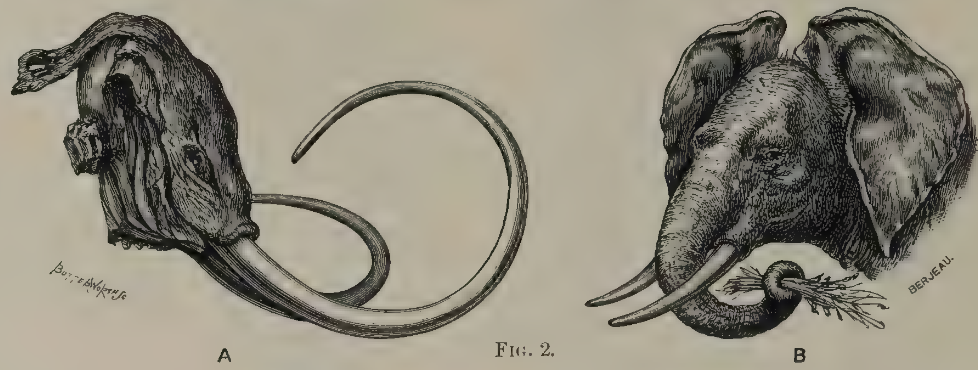


Fig. 2.

Fig. 4.

Fig. 5.

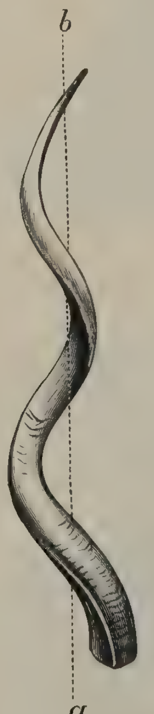


Fig. 6.

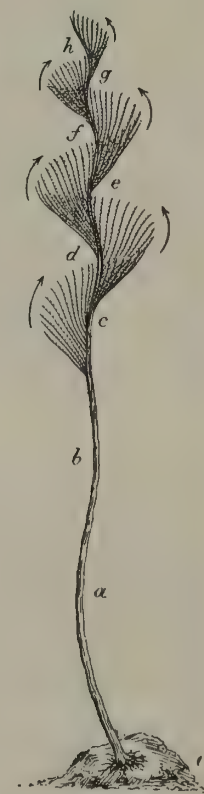


Fig. 7.

Fig. 8.

PLATE CXXIV (*continued*)

Fig. 4.—Spiral teeth of the *Barbirusa alfurus* (after Guillemard). Resemble the tusks at Fig. 2.

Fig. 5.—A. Exquisite spiral tail feathers of Wilson's bird of paradise (after Guillemard).
B. Spiral tail feathers of lyre birds, showing beautiful double curves ("Royal Natural History").

Fig. 6.—Horn of the koodoo (*Strepsiceros Kudu*) forming an exquisite open left-handed spiral. The imaginary axis (*a*, *b*) has been introduced to show how a foreign substance may be inserted within the spiral coils. Drawn by C. Berjeau for the Author from private specimen.

Fig. 7.—Corkscrew sea fan (*Streptocaulus pulcherrimus*). Forms elegant right-handed spiral (*a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*).

Fig. 8.—Skull and spiral horns of the Pamir sheep (*Ovis poli*) (after Sir V. Brooke). Shows beautiful right and left-handed spirals.

PLATE CXXV

Plate cxxv.—This plate illustrates a very interesting and little understood problem in the locomotion of the biped and quadruped, namely, how the limbs move diagonally in pairs; and how the body twists and screws at the shoulders and hips in opposite directions; the shoulders twisting forwards from right to left when the hips twist from left to right (Plate cxxvi., Figs. 6 and 7). These twisting diagonal movements occurring at the shoulders and hips produce twisting diagonal movements in the limbs and bring out to perfection the finely curved lines of the body as a whole. The most graceful of the ancient statues display the double diagonal curves referred to, Figs. 1, 2, and 3. They are also seen in the twisting and plaiting of the limbs in quadrupeds as seen in Figs. 4 and 5.

Fig. 1.—Photograph of the famous statue of the Venus of Milo. In this fine statue the shoulders and what remains of the right arm twist and screw from right to left, while the hips and the left leg screw from left to right.

Fig. 2.—Photograph of an ancient statue (Venus conquering) with the limbs intact and in position. Shows the same position and outline as Fig. 1.

Fig. 3.—Photograph of another celebrated ancient statue (Venus of Ostia) illustrating the same points. This figure exactly corresponds in outline with Fig. 1.

Figs. 4 and 5.—Instantaneous photograph of the horse in the act of walking (after Muybridge). The walking of the horse emphasises the fact that the shoulders and hips twist in opposite directions diagonally, and that the limbs not only twist diagonally, but also plait and overlap. At Fig. 4 the twisting is most marked at the shoulders and in the fore legs. At Fig. 5 the twisting and plaiting are most pronounced at the hips and in the hind legs. The diagonal twisting and plaiting movements so well seen in the fore and hind legs of the horse in walking are indicative of similar movements which occur, as explained, at the shoulders and hips. The double diagonal twisting movements so pronounced in the horse can be readily traced in other quadrupeds. They are also an outstanding feature in the walking of bipeds, and particularly man, as a reference to Plate cxxvi. conclusively proves.

PLATE CXXVI

Plate cxxvi.—This plate shows that the fish swims, the quadruped walks, and the bird flies by means of spiral organs thrown into single and double figure-of-8 curves. These curves during progression are being continually reversed, and in such a manner as enables the quadruped, the fish, and the bird rapidly to seize and let go the earth, water, and air respectively. The curved figure-of-8 movements will be readily understood by a reference to Figs. 1, 2, 3, and 4.

Fig. 1.—Represents the swimming of the sturgeon as drawn by the Author from life (1867). *a*, *b*, Line of advance; *c*, curve made by the tail and posterior portion of the fish (caudal curve of the Author); *d*, curve made by the head and upper portion of the body of the fish. These curves alternately change places as indicated by the interrupted line. The curves made by the fish and the interrupted line when taken together form double or figure-of-8 curves. The same curves are seen at Figs. 2, 3, and 4.

Fig. 2.—Double or figure-of-8 curves made by the wings of the insect, bird, and bat in stationary or fixed flight. In stationary flight the wings in passing to and fro pursue opposite directions as indicated by the arrows. In free or progressive flight the wings form a waved track. Similar tracks are made by the fish and bird in swimming, and by the biped and quadruped in walking and running.

Fig. 3.—Diagram of single and double figure-of-8 curves made by the legs and arms of a man in walking and running as drawn by the Author from life. In this figure, the continuous lines represent the legs, and the interrupted lines the arms. Man, when walking and running, advances his right leg and left arm together and simultaneously in curves to form one step, and his left leg and right arm simultaneously to form a second step. The curves made by the leg and arm are opposite, alternating, figure-of-8 curves. They are diagonal in their nature, and originate at the shoulders and hips. They are the result of diagonal twisting at the shoulders and hips in opposite directions and in the several limbs. Compare with Figs. 1 to 9 inclusive.

Fig. 4.—Vertical and horizontal curves made by the human limbs in walking and running. In addition to the curves seen at Fig. 3 there are others due to the fact that man elevates and depresses his feet at each step. There are, consequently, at least two

PLATE CXXV

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.

Fig. 5.

PLATE CXXVI

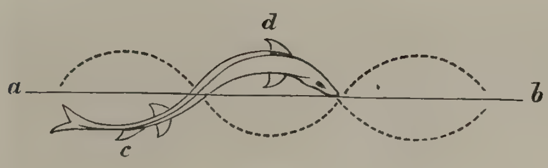


FIG. 1.

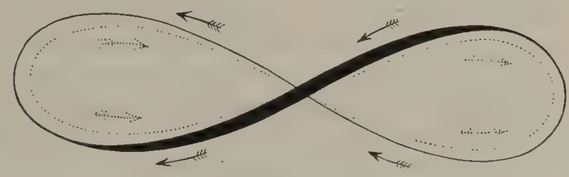


FIG. 2.

FIG. 3.

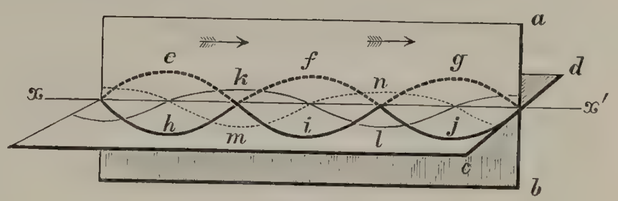


FIG. 4.

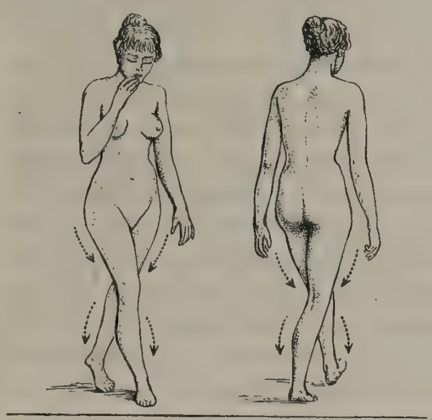


FIG. 5.

FIG. 6.

FIG. 7.

FIG. 8.

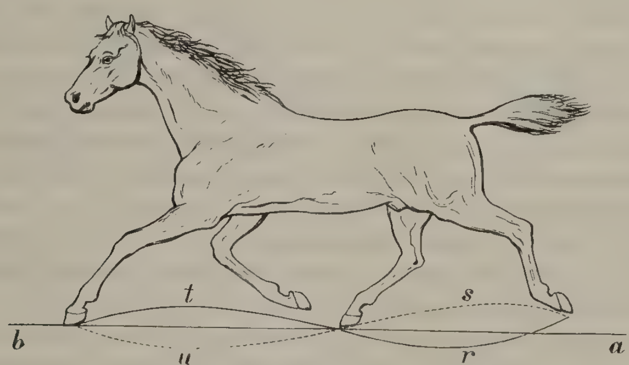


FIG. 9.

FIG. 10.

PLATE CXXVI (*continued*)

sets of curves, namely, what may be regarded as a horizontal set, which represents the lateral, twisting, diagonal movements, and a second set representing the more or less vertical ascending and descending movements of the feet. These two sets of curves run into each other at all points and in every direction by a series of oblique curves. The movements of the limbs in walking and running are characterised by a pendulum action which very greatly simplifies and reduces the effort required in locomotion. *a, b,* Vertical plane; *c, d,* horizontal plane; *x, x',* line of advance; *e, f, g,* horizontal curves made alternately by the legs and arms; *h, i, j,* ditto; *k, l,* vertical curves made by the elevation and depression of the limbs. The horizontal and vertical curves are double figure-of-8 curves, analogous to those shown in Figs. 1, 2, and 3. Drawn by the Author.

FIG. 5.—Instantaneous photograph by Muybridge of a nude female figure walking as seen anteriorly and posteriorly. The darts indicate the positions of the curves, they also show the direction in which the limbs move. The twisting and plaiting at the hips and lower limbs are well seen in this figure. It also shows that the limbs not only move in curves but that they overlap. Compare with Figs. 1, 2, 3, and 4.

FIG. 6.—Instantaneous photograph by Muybridge of a nude female figure walking on all fours—illustrates the double diagonal screwing movements occurring at the shoulders and hips—especially the latter. In this figure the hips and posterior or lower limbs are seen screwing away from the spectator.

FIG. 7.—This is the same figure as represented at Fig. 6, with the difference that the hips and posterior extremities are seen screwing towards the spectator. The individual has made a step forwards. Similar remarks apply to the shoulders or upper limbs.

PLATE CXXVI (*continued*)

Fig. 8.—Instantaneous photograph by Muybridge of a horse walking away from the spectator. In this figure the double screwing at the shoulders and in the fore legs, as well as the double screwing at the hips and in the hind legs, are accurately given (see darts). The appearance presented by the horse in this position is very striking, and nothing short of instantaneous photography could have revealed the actual facts. The diagonal twisting and screwing movements in this figure (8) are the result of double figure-of-8 movements already described. The diagonal supports in Fig. 8 are caused by the right fore limb and the left hind limb being placed on the ground at the same time. The diagonal supports referred to are also given at Fig. 10. In Fig. 10 the twisting and screwing made by the limbs are in the act of being developed.

Fig. 9.—Shows a horse trotting. The double figure-of-8 diagonal movements in this figure are revealed by a chart drawn on the sand and by experiment. *a*, *b*, Line of advance; *u*, the curve made by the left leg and foot; *s*, the curve made by the right leg and foot. The two single curves (*u* and *s*) give the half of the double figure-of-8 reversing curve; the curves (*t* and *r*) give the remaining half of the double figure-of-8 reversing curve. The diagonal supports in this case (Fig. 9) are supplied by the left anterior limb and foot and the right posterior limb and foot. Drawn from nature by the Author, 1873.

Fig. 10.—Instantaneous photograph by Muybridge of a horse walking towards the spectator. In this figure (10) the horse is in the act of reversing its diagonal supports. The horse moves alternately on right and left diagonal supports, which gives to the animal a more or less pronounced lateral rocking movement. Seven movements at least are to be predicated, namely, a horizontal, a vertical, an oblique, a forward, an elevating and depressing, a pendulum, &c. These movements all run into each other.

While it is a comparatively simple task to adduce numerous examples of spiral structures from every corner of the organic kingdom, it is by no means easy to give a satisfactory explanation of their mode of origin.

In considering the subject of spiral formation, and growth in living forms, it is necessary to bear in mind that all plants, and all animals, are more or less directly produced from the elements of the inorganic kingdom—from the atoms which form the molecules, the molecules which form the cells, and the cells which form the tissues. In other words, no plant or animal can be produced or continue to exist apart from the substances and energies which constitute the organic kingdom. Plants and animals rely upon the inorganic kingdom not only for their original matter, but also for a considerable proportion of the energy which keeps them going, and by the aid of which they are, during their lives, constantly appropriating, incorporating, and assimilating new substances, and throwing off and discharging waste or effete products. The elements of the inorganic kingdom, while they are employed in building up plants and animals at the outset, are also continually passing into and out of them, so long as they live and exercise the functions peculiar to life. The elements have, so to speak, a right of way through plants and animals.

As energy inheres in every kind of matter, it follows that plants and animals in incorporating extraneous substances into their own bodies import also the energies peculiar to those substances. The matter and energy of the universe are both represented in plants and animals. There is, however, a third and very important factor, namely, the life or inherent energy which separates plants and animals from inorganic matter as such, and from physical energy as such. The life or vital energy is a superadded energy, which controls physical energy, and the substances in which it inheres. The prerogative of life consists in the power it exerts of selecting or rejecting inorganic matter, and in employing, curbing, or neutralising physical energy.

The life is a master agency, or power, which works amongst and controls inorganic matter, and physical energy, to given ends. It makes use of physical energy when anything is to be gained by its employment, but it restrains or neutralises it as occasion demands.

The vital and physical energies are not necessarily opposed to each other. On the contrary, they work together and in the same direction to a large extent. A tree in growing upwards counteracts gravitation, but it avails itself freely of capillarity, chemical affinity, cohesion, adhesion, osmosis, and other physical forces.

There is in the universe a store of matter and of force which admits neither of increase nor of diminution, and the life freely avails itself of both in building up plants and animals, and in keeping them going and preserving them in a state of health. What the life takes from the inorganic kingdom in building up plants and animals is restored to it when the plants and animals die. There is a continuous circulation of matter through plants and animals during their entire lives. The ebb and flow, so to speak, of matter in plants and animals is as constant as the tides, and there is no period of the day or night when matter is not entering and leaving their bodies, and when force is not being transformed. This endless activity on the part of the matter and force within the bodies of plants and animals accounts for the origin, development, constitution, form, and decay of living organisms, and for the changes in appearance which they undergo during their lives; changes imperceptible from day to day, but very marked if months and years are allowed to intervene.

All the important and fundamental processes connected with the nourishment, assimilation, and growth of plants and animals are referable to atomic, molecular, and cellular changes. These changes are vital, physical, and chemical in their nature, and it is to them we must look for a solution of the problem of spiral formations in plants and animals.

That the production of spirals in plants and animals is not the result of blind chance, but is due to design and the arrangement and movement of the atoms composing the molecules of organic matter, is rendered more than probable by the remarkable researches of Pasteur, who, as has been shown, established a connection between optical activity and molecular asymmetry in organic compounds.

Pasteur says "that the molecular structures of the two tartaric acids are asymmetric, and that they are rigorously the same, with the sole difference of showing asymmetry in opposite senses. *Are the atoms of the right acid grouped on the spirals of a right-handed helix, or placed at the solid angles of an irregular tetrahedron, or disposed according to some particular asymmetric grouping or other?* We cannot answer these questions. But it cannot be a subject of doubt that there exists an arrangement of the atoms in an asymmetric order having a non-superposable image. It is not less certain that the atoms of the left acid realise precisely the asymmetric grouping which is the inverse of this."

Pasteur "regarded the formation of asymmetric organic compounds as the special prerogative of the living organism. Most of the substances of which the animal and vegetable tissues are built up—the proteids, cellulose—are asymmetric organic compounds, displaying optical activity.

"The asymmetric living organism selects for its nutriment that particular asymmetric form of tartaric acid which suits its needs—the form, doubtless, which in some way fits its own asymmetry—and leaves the opposite form either wholly, or for the most part, untouched. The asymmetric micro-organism, therefore, exhibits a power which no symmetric chemical substance, such as our ordinary oxidising agents, and no symmetric form of energy, such as heat, can ever possess: it distinguishes between enantiomorphs (mirror images). *Asymmetric agents can alone display selective action in dealing with enantiomorphs.*" Pasteur was of opinion "that compounds exhibiting optical activity *were never obtained without the intervention of life.*"

He says, "Artificial products have no molecular asymmetry; and I could not point out the existence of any more profound distinction between the products formed under the influence of life, and all others." And again, he refers to "the molecular asymmetry of natural organic products" as "the great characteristic which establishes perhaps the only well-marked line of demarcation that can at present be drawn between the chemistry of dead matter and the chemistry of living matter."

If these conclusions are correct, as Professor F. R. Japp believes,[1] they are the absolute origin of the compounds of one-sided asymmetry found in the living world, and constitute a mystery as profound as the absolute origin of life itself. The two phenomena are intimately connected, for, as we have seen, these symmetric compounds make their appearance with life, and are inseparable from it.

Professor Japp thus expresses himself: "No fortuitous concourse of atoms, even with all eternity for them to clash and combine in, could compass this feat of the formation of the first optically active organic compound. Coincidence is excluded, and every purely mechanical explanation of the phenomenon must necessarily fail.

"I see no escape from the conclusion that, *at the moment when life first arose, a directive force came into play*—a force of precisely the same character as that which enables the intelligent operator, by the exercise of his will, to select one crystallised enantiomorph and reject its asymmetric opposite.

"I would emphasise the fact that the operation of a directive force of this nature does not involve a violation of the law of the conservation of energy. Enantiomorphs have the same heat of formation: the heat of transformation of one form into the other is nil. Whether, therefore, one enantiomorph alone is formed, or its optical opposite alone, or a mixture of both, the energy required per unit weight of substance is the same.

"I am convinced that the tenacity with which Pasteur fought against the doctrine of spontaneous generation was not unconnected with his belief that chemical compounds of one-sided asymmetry could not arise save under the influence of life."

Pasteur's views, though frequently assailed by those who hold the purely mechanical theory of life, have never been successfully refuted. They are therefore in possession of the field, and entitled to all the consideration and respect which an undoubtedly great authority in chemistry, biology, and physiology confers upon them.

It will be seen from the foregoing that the right and left-handed spirals in organic compounds are traceable to the spiral arrangements and movements of the atoms composing the molecules of these compounds. They are inherent, fundamental arrangements and movements, and are in no way referable to irritability, outside stimulation, or environment. The tendency to spiral structure and movement is impressed upon the atoms from the beginning, and these arrange themselves and move in right and left-handed spirals in virtue of fixed laws which they cannot possibly set aside. The arrangement and movements of the atoms are, in short, the result of the intervention of a great First Cause.

[1] "Stereo-Chemistry and Vitalism," by Professor F. R. Japp, M.A., LL.D., F.R.S., &c., as given in the "Report of the British Association for the Advancement of Science," 1898.

The resemblances between plant and animal forms, and between them and inorganic structures, are, to say the least, very striking. Inorganic and organic growths and movements have doubtless much in common.

Of course it may be argued that this similarity of form and movement between living and dead things points to a common origin—that origin being physical in its nature. Similar laws are at work, no doubt, but living and dead matter deport themselves so differently under all circumstances that it is more reasonable to suppose that the First Cause has created types to which living and dead matter may conform without serious dislocation or disturbance to either. If it is, as I believe, a case of give and take all round, as between living and dead matter, and between what is practically vital and physical force, it is easy to understand how organic forms and movements may resemble inorganic ones, and how vital and physical force may assimilate and blend to such an extent as to create a belief that there is only one kind of force. If, however, there is living and dead matter (and this is admitted) it is logical to infer that there is also vital and physical force.

There are many facts which tend to show that spiral growths and formations in plants and animals are due to original endowment residing in the atoms and the molecules composing them. That the spiral formations are fundamental is abundantly proved by the fact that they appear in the germs, seeds, and eggs of both plants and animals when they cannot possibly have developed the so-called irritable tendency, or have been exposed to the influence of external stimuli. The germinating particles develop in particular directions, and along given lines, in virtue of powers implanted in them, and apart from environment.

The germs, seeds, and eggs are independent entities from the first, and they fulfil their destinies, of themselves, and by themselves, provided the conditions of growth are supplied. One series of germinating particles develops a right-handed spiral, another series a left-handed spiral, but (and this is the important point) the particles evolve and assume the right or left spiral form not because of extraneous pressure or adventitious circumstances, but because they are, from their constitution, obliged to assume the shape in question and no other; the atoms and molecules only lending themselves to the building up of the particular shape required in each particular case. No mistake ever occurs in the production of right and left-handed spirals as structural units. As only certain plants and animals can be developed from certain germs, seeds, and eggs, so right and left spirals which, from the first, are fundamentally different, never get mixed up or lose their identity.

What holds true of the spirals formed by germs, seeds, and eggs, also holds true of adult forms. Spiral structures in great plenty, as has been already shown, occur in all parts of plants and animals. Plants, for example, turn or climb with or against the sun. The sun's heat does not therefore produce the spiral climbing movements to right or left. Plants which climb to right or left do this with or without a support: in other words, the contact with a foreign body and the supposed stimulation or irritation believed to be produced thereby are not necessary to the climbing process. Plants twist their stems to right or left and form right or left-handed spirals apart from light, heat, and contact. They do the same when not in contact with supposed stimuli. They sometimes twist one portion of their stem into a right-handed spiral and another portion of it into a left-handed spiral as in the case of the hop and the tendrils of the passion-flower (Plate cxv., Figs. 1 and 2). No stimulus or irritation can possibly produce these alternating opposite spirals. They are wholly due to vital action and original endowment. It is not conceivable that the same stimulus or irritation applied to different parts of the same plant could produce diametrically opposite results apart from vital peculiarities in the stem itself.

Similar remarks are to be made of animals.

Shells form every conceivable kind of spiral. The animals which occupy the shells construct their exquisite spiral external skeletons according to fixed laws and apart from every form of external stimulation and irritation (Plates cxix. and cxx.). Similarly, antelopes and other animals grow beautiful spiral horns altogether apart from extraneous circumstances (Plates cxxi., Fig. 2, and cxxiv., Figs. 6 and 8). In like manner the spiral arrangements of muscles, bones, and joints in birds and mammals are all due to original design and endowment (Plate cxxiii., Figs. 1 and 2). In the several cases mentioned, the conditions of growth do not essentially differ. Certainly irritability and outside stimulation do not figure as factors. Spiral growth in plants and animals is a necessity of their being, from the fact that the atoms and molecules forming their tissues and organs positively refuse to assume other than spiral shapes. The spiral shapes here alluded to can only be explained by original endowment. There is no getting behind this, and irritability, sensitiveness, extraneous stimulation, &c., take little or no part in the production either of the spiral structures or of the spiral movements.

All the spiral formations are, it appears to me, the result of unequal spiral growth; the developing mass having impressed on it, at the outset, an irresistible tendency to grow more on the one side than on the other. The growth in question is a highly complex process produced by the spiral arrangements and movements of the atoms and molecules forming the cells and the tissues, whether they be hard or soft.

The single spiral is always one-sided and non-symmetrical. To have perfect symmetry, there must be at least

two spirals or spiral segments. In the single spiral it can readily be conceived that one half, or a certain proportion, of the growing mass, is more active than the other, and that the quicker growing portion keeps steadily pushing the slower growing portion aside until the spiral form is assumed.

It is not conceivable that the spiral formations and movements of plants and animals are the result of chance. They must be provided for from the beginning. The atoms of matter must be made to act in specific directions and to assume certain definite forms. It would not be possible for matter and force to achieve the marvellous results which are accomplished by plants and animals apart from these considerations. The beauty of form and movement in plants and animals are both referable to fundamental arrangements. The endless repetition of structure and of function—identical as a rule in their details—proclaims a governing principle, and the operation of unalterable laws.

There are very special grounds for believing that the organic kingdom is quite as much regulated by law and order as the inorganic. There is, however, this difference : the forces and matter of the organic are much more subtle, and the combinations and reactions much more numerous, than in the inorganic. It is not reasonable to suppose that dead, unfeeling matter should be more cared for than living, sentient matter, and that the inorganic kingdom should be controlled by beneficent laws which are denied to the organic.

The mystery, an apparently inscrutable one, consists in the fact that the various kinds of spirals in plants and animals reappear in the same places, and in the same species and genera, with unerring regularity. Thus, certain plants twine from right to left, while others twine from left to right. It happens occasionally that in the same plant the spirals run for some little distance in one direction, and then reverse and run in exactly the opposite direction. In such cases the plant apparently endeavours to correct a unilateral tendency, and so to equilibrate and set up what is, virtually, a bi-lateral symmetry.

Spirals seldom, if ever, get mixed up. Thus the four sets of spirals (two external and two internal) forming the left ventricle of the heart in the bird and mammal, while they run in opposite directions, are always distinct (Plate xcvii., Figs. 9, 10, 11, 13, 14, and 15). Similarly, the spiral nerves of the said ventricle, while they cross the spiral muscular fibres at nearly right angles, never lose themselves. The same may be said of the double spirals met with in the ganglion nerve-cells of the frog, &c. (Plate cxviii., Fig. 5, A, B).

Spirals, however produced, are entitled to great consideration because of their utility.

Spirals, as explained, occur in both the inorganic and organic kingdoms. In the latter they are perhaps found in greatest variety in the Foraminifera, those exquisite microscopic points which, for beauty of form and colour, are, in many instances, matchless.

The spiral is, in a certain sense, co-extensive with life. It reveals itself in the lowest vegetable and animal forms, and can be traced through them to the highest.

It is, moreover, not confined to the existing order of things. It is to be seen to-day in the tender jelly-fish, and in the pulpy microscopic cell ; and in past ages it revealed itself in the huge, hard, ivory tusks of the mammoth.

As the spiral arrangements and movements in the organic and inorganic kingdoms are all traceable to atomic molecular changes, it is necessary at this stage to take a wide view of the subject, and to deal with force (physical and vital), atoms, molecules, cells, tissues (especially muscles and nerves), growth, reproduction, &c.

It will not be possible otherwise to understand the movements in plants and animals and of bodies in space. A knowledge of matter and force is indispensable to a just comprehension of growth, of form, of function, and of those endless actions and reactions which are continually occurring between the organic and inorganic kingdoms.

It has been already shown that the formation and movements of certain of the heavenly bodies are not unlike those of certain cells, seeds, ova, &c., and that plants and animals resemble each other remarkably both as regards ultimate composition and shape.

A consideration of these various subjects may, at first sight, appear outside the scope of the present work, but a little reflection will show that matter and force in their various combinations underlie every possible structure and every possible movement. It consequently behoves us to treat of organic and inorganic matter, and of vital and physical force, in a general sense, and to discuss the combinations and interactions peculiar to and common to all.

As inorganic matter precedes organic matter, and physical movement precedes vital movement, it follows that matter and force must be studied together if an adequate view of the subject is to be obtained.

SPIRAL FORMATIONS IN PLANTS

§ 202. Spirality in Plants the Product of Life and Original Endowment.

Plants, as is well known, may be propagated in various ways. Usually they are the product of seeds, and the seed consequently is an object of great importance in the present inquiry.

It will be correct to say that the plant develops or grows from the seed on particular lines, and that like seeds always produce like plants; a grass seed, for example, never giving rise to a plant of wheat, or a grain of wheat to a plant of maize. This proves original difference and endowment, not only in the seeds, but also in the component parts of the mature plants.

Plants differ from each other intrinsically. Each plant has its own special form and qualities, and fulfils its own particular destiny. It resembles other plants only up to a certain point. Plants, however, have this in common: they are all living, aggressive entities continually engaged in seizing, appropriating, digesting, assimilating, and dismissing dead matter of various kinds. They are never passive in the sense that they only act in response to artificial stimuli, and because of a supposed inherited irritability of constitution. Plants are not goaded into activity by their surroundings. They live and move because of the life which originated, which built them up, and which keeps them going. Similar remarks, but in a higher sense, are to be made of animals. It is a mistake to suppose that plants and animals are, to any extent, the playthings of circumstance. On the contrary, they have an independent and great rôle to perform in the economy of nature. The life is to be accredited not only with the origin and building up of plants and animals, but also with the discharge of all their functions and movements. They live and move to given ends purposely, apart from so-called irritability and artificial stimulation.

Plants and animals are in every case more or less sensitive; but sensitiveness and irritability are not co-extensive terms. Sensitiveness does not necessarily imply discomfort and uneasiness; irritability implies both. Irritability is a supposititious attribute; sensitiveness is a real attribute, conferred upon plants and animals for their guidance and to enable them to deal effectively with the foreign substances which are being continually taken into and ejected from their bodies. Irritability implies a state of constant excitement and unrest which requires for its exercise artificial stimulation and which, I venture to assert, does not exist. Sensitiveness, on the other hand, implies a latent power, peculiar to living things, which is evoked at intervals when a plant or an animal touches, or is touched by, the extraneous matter by which it is surrounded, and amongst which it lives. In animals there is a sensitiveness of mind as well as of body.

The sources of the activities of plants are seen to advantage when a thin longitudinal section of a stem is placed under the microscope. A bewildering number of spiral cells, and spiral and other vessels and tissues meets the eye; and these all take part in the circulation and distribution of sap, &c.

The stem of a growing plant reveals a plethora of capillary and other currents longitudinal, transverse, and oblique. It is as busy as a bee-hive, and forms the means of communication between the roots, branches, and leaves. Sap of all kinds is continually rushing hither and thither, especially during summer.

The crude and elaborated products of plant life pass along the stem and find an asylum; it being there that sugar, starch, and other materials are stored and rendered available for the nourishment of the plant during winter, when the roots are less active, and the leaves, in the majority of cases, have disappeared.

The stem, more than any other part, represents the growth and the age of the plant.

The mode of production of the currents in plants and the direction thereof, especially the longitudinal and transverse ones, is indicated at Figs. 88 and 89, p. 432, and Figs. 101, 102, and 103, p. 435.

Spiral structures are not confined to the seed and the stem. They are found also in the arrangement of the branches, the leaves, flowers, fruits, &c. The whole internal and external economy of the higher plants is based upon spiral types, and the various spiral structures in the living plant are living structures.

As the moisture, nourishment, and heat supplied to spirally growing parts have nothing of spirality in them, it follows that the spiral formations are the products of life, which forces the atoms and molecules forming the cells and tissues into definite and enduring spiral shapes in endless variety.

The living seeds, living cells, and vascular bundles, and the living stem all twist upon themselves. The living branches, moreover, are arranged spirally on the stem, the leaves are coiled up spirally and distributed in spiral cycles, the flowers are disposed in spiral whorls, and the whole plant is, or may be, a congeries of spiral structures.

According to Dutrochet there is a revolving movement in the summit of stems, a spiral rolling of the stems round their supports, a torsion of the stems on themselves, and a spiral arrangement of leaves—all these being in

each plant in the same direction. These phenomena, he adds, are owing to an internal vital force, which causes a revolution round the central axis of the stem.[1]

A living plant may be said to literally screw itself into the ground by its roots, and out of the ground and into the air by its stem, branches, leaves, flowers, and fruit.

With these facts before us, it would be rash to assert, or seriously maintain, that inherent irritability and contact with extraneous and adventitious substances have anything to do with the production either of plant spiral structures or of plant spiral movements.

Plants, as stated, are not dependent upon fortuitous circumstances either for their origin, their substance, or their energy. All these are assured from the beginning. When, therefore, we are told that the great races of plants and animals largely owe their origin and existence to a supposed inherent irritability of constitution which requires for its manifestations ever recurring contact with dead matter, we are virtually asked to believe that inert matter and physical force are superior to living matter and vital force; that dead matter leads, and living matter follows; that plants and animals are automata; and that life, and all the relations of living things, are mere questions of environment and mechanics.

So strongly am I impressed with the inherent powers of life, as witnessed in living plants and animals, that I feel the time has now arrived when the terms "irritability" and "stimuli," as supposed factors in physiology, should be abandoned. Their employment has, it appears to me, placed the physiology of plants and animals in an altogether false light.

I shall have occasion to return to this subject further on.

Contraction is another term which has caused much misconception and confusion in physiology, and should be given up. Strictly speaking it means a shrinkage, a diminution in volume. It is, however, constantly employed in modern physiology to indicate movements in living substances where no diminution in bulk occurs. The remark applies not only to protoplasmic, but also to muscular movements.[2] It would be much more correct to say that substances increase or diminish, lengthen or shorten, open or close, &c.; and these are the terms I propose to employ in the present work.

There are other objectionable terms at present in use, such as instinct, unconscious cerebration, and, within limits, reflex action, which an advanced physiology will sooner or later discard.

§ 203. Spiral Seeds.

The subject of spirality is well illustrated in the case of spiral seeds, where no questions as to inherent irritability or artificial stimulation, such as are said to be required to explain the structure and movements of climbing plants, can either be raised or admitted.

The spiral seeds have a wide range.

One of the simplest is that of the common ash, where the seed is elongated and ribbon-shaped, and merely twisted upon itself as any narrow, flat, flexible material might be twisted between the fingers and thumbs. The twist is made by the seed turning or screwing upon itself to the extent of nearly a half turn; the spiral running from the right to the left of the spectator as shown at Plate cxvii., Fig. 1, p. 646. It is convenient to speak of spirals as running from right to left or from left to right of the spectator as they appear on the printed page and as he there contemplates them.[3]

The seed resembles a blade of the screw propeller of a steamship.

The spiral configuration of the seed of the ash is caused by the spiral arrangement of the atoms and molecules composing the protoplasm from which the seed is produced. The shape assumed is due to life and original endowment. In other words, it is not occasioned by a supposed irritability in the seed itself, or by contact with a foreign substance, supposed to furnish an artificial stimulus.

This follows because the seed grows free in space, and is not in contact with anything but the atmosphere.

It is important to emphasise this fact, as the majority of botanists and physiologists of the present day maintain that the spiral structures and movements of plants—especially climbing plants—are due to irritability of constitution and contact with foreign bodies. I shall have to deal with the climbing plants presently, but I think it right, at the outset, to express my conviction that all spiral structures and movements in plants, and likewise in animals, are in no way connected with inherent irritability or extraneous stimulation, but are, in every instance, the outcome of original endowment in which the life occupies the first position and plays the leading rôle.

[1] "Braun sur les torsions normales dans les plantes."
[2] Some investigators think they have succeeded in showing that a muscle when it contracts becomes smaller: others, however, maintain that there is no change whatever in size, and that the methods employed to demonstrate the point are fallacious.
[3] On the Continent it is customary to describe spirals as if the spectator were placed within them.

The spiral seed of the ash is deserving of special attention because of its beautiful twisted, screw-like shape, and the obvious purpose to be served by it. It forms one of the so-called winged seeds, the object to be accomplished by its flattened spiral form being to retard its fall in autumn, and give the wind an opportunity of wafting it some considerable distance from the parent tree. By this arrangement the seed is enabled to plant itself in fresh soil at a distance from its progenitor.

Perhaps the best example of a winged seed is that furnished by the plane tree (Plate xcvi., Fig. 4, p. 420). This seed consists of two symmetrical halves which are united in the middle and depend from one stem. It remarkably resembles a winged creature, such as an insect, a bird, or a bat: that is, the seed has a body, and two highly-elaborated wings, each wing being perfect structurally. Thus each wing is triangular in shape, and tapers from the base to the tip, and from the anterior margin to the posterior margin. Each wing is also supplied with delicate, tapering, supporting structures, which radiate from the base and anterior margin towards the tip and posterior margin, as in the nervures of the wing of the insect, the primary, secondary, and tertiary feathers of the wing of the bird, and the arm and phalangeal bones of the wing of the bat. The wings are also slightly twisted upon themselves when fully matured and ready to fall.

The greatly expanded winged seed of the plane tree is admirably adapted to discharge an obvious function. When the seed falls at the end of the year it makes a comparatively slow, spiral descent, and, if a wind be blowing, it is caught *in transitu* and often carried considerable distances. This is one of nature's methods for distributing trees and forming forests. The birds perform a like function when they swallow and drop seeds occasionally miles distant, and not unfrequently in inaccessible regions, where no human hand could plant them.

One of the most striking arrangements of spiral seeds is to be seen in the fir cone (*Pinus*), where the seeds and the scales, or metamorphosed leaves, which cover them, are disposed in right and left-handed spirals which mutually intersect each other, as indicated by the darts at C of Fig. 6, Plate cix., p. 628.

According to Professor J. H. Balfour one generating spiral runs through all the scales of the cone, there being a number of secondary spirals which run parallel to each other and indicate the difference between each scale to a single spiral.

At A and B of Fig. 6 of Plate cix., p. 628, the spiral arrangement of leaves on the stem is illustrated. The leaves forming spiral cycles run from two upwards. At A and B the spiral cycle consists of seven leaves. At A, the divergence between every two leaves is $\frac{3}{7}$. At B, the divergence between every two leaves is $\frac{1}{7}$. This subject is fully discussed further on.

Another striking example of a fruit with its numerous flowers and bracts united, and spirally arranged, is to be seen in the pineapple (*Ananassa sativa*).

§ 204. Spiral and other Cells in Plants.

These are seen in great numbers in the stems of plants. They occur as elongated separate cells, many of which have spiral fibres wound round them. Not unfrequently the cells unite to form vessels which display spiral fibres in their walls. Other vessels are composed of annular and reticulated fibres.

It happens occasionally that the spiral and other cells of plants display in their interior a spiral or rotatory movement of fluids and granules, which is very mysterious, and can only be accounted for by the direct interposition of life. The spiral movements within the cells of Chara are seen at Fig. 107, p. 438: the rotatory movements within the cells of Vallisneria at Fig. 109, p. 438: at Figs. 108 and 110, p. 438, the circulation within the stem of a polype and in lactiferous vessels is given for the purposes of comparison.

§ 205. Spiral Fronds, Leaves, and Flowers.

Few better spiral formations can be adduced than are furnished by the fronds of the fern (Plate cxvi., Fig. 4, p. 644).

One of the most beautiful examples of a whorl of twisted leaves is met with in Alstrœmeria, where the leaves, five in number, crown the stem as seen in Plate cxvii., Fig. 2, p. 646.

§ 206. Spiral Hairs, &c., of Plants.

These remarkable appendages are found in considerable numbers on the stems, roots, branches, leaves, and seeds of plants. Representations of them as seen more especially in seeds are given at Fig. 224.

§ 207. Spiral Distribution of Leaves and Branches.

The leaves and branches may be regarded as the product of the stem or ascending axis of plants. The stem is the central structure to which all other structures are referred, and to which they bear a fixed relation.

Plants are named according to the duration and nature of their stems: thus there are annual herbs when the stem dies down each year; biennial herbs when the stem dies at the end of every two years; and perennial herbs when the stems survive for many years.

Plants producing permanent woody stems are classed as shrubs and trees.

The stems of trees grow, and are added to, in three different ways. In the acrogens or top growers, the additions are made to the stem at the top, as in the tree ferns; in the endogens, the additions are made from within, as in the palms; and in the exogens, the additions are made from without, as in the Scotch firs.

The stem, however, is considered by some to be formed of a series of leaves, at first closely aggregated on a shortened axis, and afterwards separated by more or less evident intervals. As the leaves decay and fall off, the stem becomes more conspicuous and uninterrupted.

The parts which belong to the stem, and which require to be separately described, are the leaves, buds, and branches.

These spring from projections or *nodes* on the stem, and are separated from each other by spaces called *internodes*.

The internodes mark the distance between the leaves, buds, and branches, respectively.

"The nodes are distinguished by the leaves which they bear, or by the scars produced by the fall of the leaves.

"Buds may be regarded as shortened leaf-bearing axes, capable of elongation so as to form stems and branches. Some buds are terminal, or are produced at the extremity of the primary axis, where, in some cases, they produce a spiral whorl of leaves; other buds are lateral, or are produced on the sides of the stem, where they are spirally arranged. The buds are situated at the angles where the leaves join the stem."

Leaves, buds, and branches, in the higher plants, are distributed spirally round the stem or central axis, and their orderly arrangement forms a most interesting subject of study. The following is the account given of them by Professor J. Hutton Balfour.[1]

The distribution of leaves on the stem (phyllotaxis) is simple when the leaves are few and the spiral cycle made by them short; but it is intricate, and even perplexing, when the leaves are numerous, and the spiral cycle made by them long.

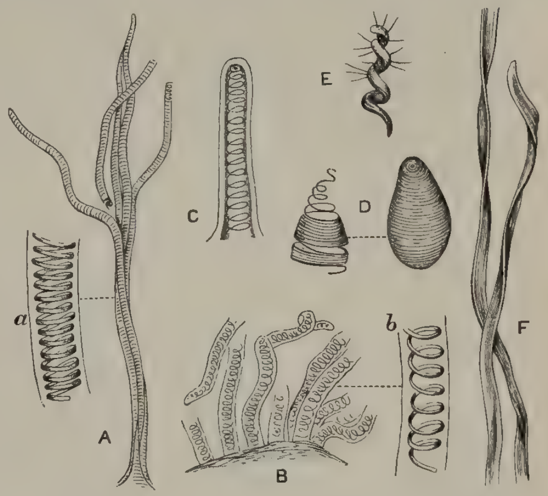


FIG. 224.—A. Spiral hair from the seed of *Acanthodium spicatum*, × 50. *a*, Spiral fragment from a branch, × 200. The hair is composed of spiral fibres and, in addition, twists upon itself.
B. Spiral fibrous hair from the seed of *Collonia grandiflora*, × 50; *b*, fragment showing the free spiral fibre.
C. Spiral hair from the seed of *Salvia*, × 50.
D. Spiral scale-like hairs from the seed of *Cobœa scandens*, × 50 (after Griffith and Henfrey).
E. Spiral spermatozoid, with cilia: from the antheridian cells of the prothallium of a fern, *Asplenium septentrionale* (after Balfour).
F. Spiral hair from the seed of the cotton plant, × 100.

The distribution of leaves is regulated by certain definite laws, and depends on the development of the nodes and internodes of the stem and branches. When the internodes are so short that the stem is apparently wanting, the leaves are denominated *radical*, as in the cowslip and dandelion.

In this case the arrangement of the leaves is difficult to make out. The phyllotaxis, or leaf arrangement, becomes easy in proportion as the nodes are separated from each other. When each of the nodes on an elongated axis produces a single leaf, the leaves are said to be *alternate*, because they are placed alternately on different sides of the axis. When two leaves are produced at a node, they are called *opposite*, because they are situated on opposite sides of the axis, while the production of three or more leaves at a node gives origin to a circle or whorl of leaves, which are then said to be *verticillate*.

Alternate leaves are very common.

The simplest arrangement is that in which the third leaf is placed directly above the first, while the second is placed on the opposite side of the stem and separated by half the circumference of the circle. In this case there are two rows of leaves, one on each side of the stem, and the arrangement is said to be *distichous*. When, following the same principle, the fourth leaf is placed above the first, the arrangement is *tristichous*, or in three rows. When the fifth leaf is placed above the first, and there are four rows, the arrangement is *tetrastichous*. In the case of

[1] "Introduction to the Study of the Vegetable Kingdom." ("Class-book of Botany.")

the sixth leaf being placed over the first, as in the branch of the oak with six alternate leaves, the arrangement is *pentastichous*, or in five rows, and so on.

It will be observed that in following the course of the alternate leaves on the stem a spiral screw-like method is adopted, and that the termination of the spiral cycle is to be found in the leaf directly above that from which a commencement was made.

The number of spiral turns made by the leaves on the stem depends on the number and distribution of the leaves themselves.

In the distichous or two-leaved arrangement, one turn is made. In the pentastichous, or five-leaved arrangement, two turns are made. The latter arrangement is marked by a fraction where the numerator represents the number of turns round the stem, and the denominator the number of leaves in the spiral cycle. The fraction in turn gives the angular divergence of the leaves, or the distance between the leaves expressed in parts of the circumference of the circle.

Thus the fraction $\frac{1}{2}$ denotes distichous leaves, the angular divergence being one half of the circle or 180°; the fraction $\frac{1}{3}$ denotes tristichous leaves, the angular divergence being one-third of the circle or 120°; the fraction $\frac{2}{5}$ denotes pentastichous leaves, the angular divergence being 144°.

From these data it is easy to construct a table giving the divergence of the leaves and their modifications in dicotyledons, monocotyledons, and acotyledons.

The following table, with illustrative examples, may be of service :—

DIVERGENCE	EXAMPLES
$\frac{1}{2}$	Lime, *Cyperus*, *Fissidens*.
$\frac{1}{3}$	*Cereus triangularis*, *Carex*, *Gymnostomum*.
$\frac{2}{5}$	Pear, poplar, *Eleocharis acicularis*.
$\frac{3}{8}$	Holly, *Lilium candidum*, *Lycopodium Selago*.
$\frac{5}{13}$	Wormwood, *Agave americana*, *Lastrea Filix-mas*.
$\frac{8}{21}$	Cones of *Pinus picea*, *Gymnadenia conopsea*, *Hypnum alopecurum*.
$\frac{13}{34}$	*Euphorbia cæspitosa*, cones of some pines, *Yucca aloifolia*, *Sphagnum*.
$\frac{21}{55}$	*Mammillaria coronaria*, cones of some pines.

It will be evident from the foregoing, that the buds, leaves, and branches, in the several kinds of plants, are arranged in spiral cycles, in a given order, and according to a definite plan which is never departed from. In other words, there is law and method in the arrangement of the different parts of plants. Nothing is left to chance. The arrangement in the majority of cases is mathematically exact.

The origin, growth, and maturation of plants are all due to life, and the operation of a First Cause, which determine their structural peculiarities and the flow of sap and other matters in particular directions. The same causes control the movements of animals.

It is not conceivable that results so definite could be achieved by the operation of external forces or fortuitous extraneous substances, apart from a vital or master force acting under the influence of fixed laws.

External matter and physical force can achieve nothing unless guided by vital force and a First Cause. The latter subordinate matter and cause it to assume certain shapes, and to perform functions which could not possibly be performed by inanimate matter, whatever its degree of elaboration. Plants are superior to their environment. The life, and not the environment, takes the lead. The modifications in plants, and likewise in animals, are traceable rather to vital than physical changes. The changes are internal rather than external.

§ 208. Spiral Stems of Plants and Boles of Trees.

Perhaps the most striking illustrations of spiral formations are to be witnessed in the stems of plants and the boles of trees. The greater size of the stems and boles naturally attracts attention. Apart from size the twisted form is, in many cases, very conspicuous, as for example in the screw pine (*Pandanus*).

The spiral stem and bole are the direct outcome of the life working through the atoms and molecules which form the cells, spiral vessels, and other tissues of plants and trees.

It is believed by some that the spiral arrangement of branches and leaves contributes to the spiral formation of stems and boles. I am of opinion that it is just the other way, and that, as a rule, the spiral stems and boles

produce the spiral arrangements of the branches and leaves. This seems the more natural as the stems and boles precede the branches and leaves.

There are spiral stems and boles where there is no spiral distribution of branches and leaves, and the converse; but the rule is that when branches and leaves are spirally arranged on stems and boles, the stems and boles themselves are twisted, and display the spiral configuration.

The spiral stems and boles of trees occur more frequently than is generally imagined, and a little attention to the subject will prove the accuracy of this statement.

I have been frequently struck when splitting bamboo and other canes, and timber generally, to find a well-marked tendency to spiral cleavage.

The stems of plants often twist or screw in two opposite directions, and thus make alternately right and left-handed spirals. The stems also, in many cases, twine round artificial supports. The common hop does both.

One of the best examples I have ever seen of a large, twisted bole, came under my observation a few years ago when on a visit to the famous island of Inchmahome, otherwise called the "Isle of Rest," in the Lake of Menteith. Here the beautiful Mary Queen of Scots spent part of her happy childhood with the other little Marys, her childish companions. Here too is to be found the Queen's Child Garden, so touchingly described by the famous Dr. John Brown of Edinburgh, author of many delightful papers entitled "Horæ Subsecivæ."

The Queen's Child Garden was discovered by my venerated teacher and friend, the late Mr. James Syme, Professor of Clinical Surgery in the University of Edinburgh, and one of the greatest surgeons Scotland has ever produced.

Professor Syme and Dr. John Brown were greatly attached to each other, and, in a sense, inseparable. What the discriminating penetration of the one pointed out, the genius of the other embellished, and hence that most charming brochure of Brown's known as "Queen Mary's Child Garden."

With delicate artistic touch he thus delineates the fairy scene: "On the unruffled water lie several islets, plump with rich foliage, brooding like great birds of calm. You somehow think of them as on, not in, the lake, or like clouds lying in a nether sky—'like ships waiting for the wind.' You get a coble, and a *yauld* old Celt, its master, and are rowed across to *Inchmahome, the Isle of Rest.* Here you find on landing huge Spanish chestnuts, one lying dead, others standing stark and peeled, like gigantic antlers, and others flourishing in their *viridis senectus*, and in a thicket of wood you see the remains of a monastery of great beauty, the design and workmanship exquisite.

"You wander through the ruins, overgrown with ferns and Spanish filberts, and old fruit trees, and at the corner of the old monkish garden you come upon one of the strangest and most touching sights you ever saw—an oval space of about eighteen feet by twelve, with the remains of a double row of boxwood all round, the plants of box being about fourteen feet high, and eight or nine inches in diameter, healthy, but plainly of great age.

"What is this? It is called in the guide-books Queen Mary's Bower; but besides its being plainly not in the least a bower, what could the little Queen, then five years old, 'and fancy free,' do with a bower? It is plainly, as was, we believe, first suggested by our keen-sighted and diagnostic Professor of Clinical Surgery, *the Child Queen's Garden*, with her little walk, and its rows of boxwood, left to themselves for three hundred years. Yes, without doubt, 'here is that first garden of her simpleness.' Fancy the little, lovely royal child, with her four Marys, her playfellows, her child maids of honour, with their little hands and feet, and their innocent and happy eyes, pattering about that garden all that time ago, laughing and running, and gardening as only children do and can." [1]

It is with the "huge Spanish chestnuts," and especially with the "one lying dead," that I have to do.

This fallen giant attracted my attention, and made such a profound impression on me that I had it photographed by a dear young friend, I. Maclay.

It is faithfully reproduced from the photograph in Plate cxiv., Fig. 2, p. 641, and is one of the best examples of a great, twisted bole to be anywhere seen. The venerable recumbent monarch at its root end has a girth of fifteen feet, and at its top end a girth of nine feet. The tree has been sawn through about eighteen inches above the ground, and lies where felled, being, in all probability, too large and heavy to remove.

The great dimensions of the tree may be inferred from the relative size of the tall stone dyke behind it, which, with trees, forms the background of the picture.

The spiral of the bole runs from left to right of the spectator, provided the bole be regarded as in the vertical or growing position.

§ 209. Spiral Fossil Stems.

Of late years some remarkable spiral fossil stems have been brought to light in a region known as the "Bad Lands" in Nebraska, which forms part of the great basin to the east of the Rocky Mountains.

[1] "Horæ Subsecivæ": second series, by John Brown, M.D., F.R.S.E., pp. 171 and 172.

The spiral fossils have been vulgarly called "Devil's Corkscrews," and "Spiral Twisters," from a belief that they must be of supernatural origin.

They have been investigated by Mr. Darton of the United States Geological Survey; Doctors Biggs and Farrington of the Field Columbian Museum, Chicago; Dr. Scott of Princetown; and especially by Professor E. H. Barbour of Nebraska University.

They occur in vast numbers on hill sides and rocky faces, and can be traced over the western half of Nebraska into Wyoming.

"Within an area of about 500 square miles in Nebraska there are literally millions of these curious objects, revealed to view by being 'weathered out' of the sandstone formation. They are composed of quartz, and every one of them is carried out with a precision that might be expressed by a mathematical formula."

In addition to being exposed by water and wind action, they are dug out with pickaxes and other sharp implements.

The spiral fossils are of gigantic proportions, and measure from fifteen to twenty feet and upwards in height.

They present this notable feature, that some of them twist from right to left, and form right-handed spirals; while others twist from left to right, and form left-handed spirals. This, it may be remarked, is not an uncommon feature in climbing plants, and in plants with twisting, spiral stems.

Various theories have been propounded as to the origin of the so-called Devil's Corkscrews.

One theory is that they are the remains of huge spiral worms which assumed a vertical position in the expectation of food.

Those who hold this view declare that great worms would be quite natural in a region where great fossil reptiles, some of them ninety feet in length, abound.

Another theory is, that the corkscrews represent the moulds of spiral burrows made by a small rodent, named the gopher. This is known as the "gopher hole theory."

The gopher does great harm to crops of all kinds by eating the roots of the plants. Ages ago, the prehistoric gopher is believed to have excavated the spiral burrow by a "mathematical instinct," and to have made its nest in a large branched chamber at the termination of the burrow. This was the first stage of the formation of the corkscrew. The second consisted in the continuous flooding of the burrow by water containing silica, which, in process of time, gradually produced an accurate quartz mould of the original spiral excavation.

A third theory, now generally accepted, is, that the fossil spirals represent spiral water plants.

The third theory was propounded by Professor E. H. Barbour of Nebraska University. According to his account and that of geologists: "The great basin to the east of the Rocky Mountains, including the area now called Nebraska, was a vast lake a million years or so ago. That was the epoch known as the Miocene, when as yet the North American Continent was in process of formation. On the bottom of this fresh water sea, at a depth of hundreds of feet, grew immense numbers of water weeds of a species unknown to-day. They were of gigantic size, some of them twenty feet or more in height, and they assumed the form of huge spirals, mathematically exact in their curvature. It is imagined—though of this there is no positive proof—that each one was made up of a group of plants, together forming a sort of community. Rivers brought into the inland sea immense quantities of detritus, and this was deposited on the bottom of the lake so rapidly that whole fields of the giant water-weeds were buried beneath it. In the course of ages the lake-bottom became dry land, and incidentally the plants, decaying, were replaced, particle by particle, by silica deposited from water which contained it. Silica forms the material basis of quartz, and thus it is that the so-called Devil's Corkscrews were formed, reproducing in rocky substance the vegetables from which they originated. Weathered out from the cliff-sides in these later days, they stand in rows like sculptured pillars twisted into spirals. Unlike ordinary corkscrews, they turn not all one way, but are right-handed as often as left-handed. Anybody might well suppose them to be works of art, so graceful and elegant are they. Some of them wind about a vertical axis, like a vine around a stick, but others are free."

That the Devil's Corkscrews are of plant origin there can, I think, be little doubt. This seems proved by the fact that they have, when perfect, a great expanded, triangular-shaped, branched portion at the bottom or lowest part corresponding with the root of a plant. The root is three-pronged; the part above the prongs being round, and, in some cases, thicker than a man's body. In a large specimen, the root is sometimes twenty feet long.

My own impression is that the corkscrews are unquestionably of plant origin, but that the spiral stems are produced, not by water plants, but by ordinary climbing plants, and in a slightly different way from that indicated by Professor Barbour.

I believe that the spiral fossils are produced by climbing plants twining round separate, non-climbing or straight plants; the climbing plants partially strangulating, within their folds, the non-climbing, straight plants, and producing continuous, spiral bulgings in the latter. The effect of the strangulation is to prevent the ascent of sap in

vertical lines, and to compel it to flow in spiral lines, with the result that the original non-climbing, straight stem is, by a process of growth, gradually converted into a spiral stem; the straight plant and the spiral climber, in course of time, intertwining and mutually embracing each other.

While each fossil corkscrew is originally composed of two distinct plants, as explained, it happens occasionally that only one of the two plants is represented in the fossil, the other having disappeared, by a process of decay, while the fossil was being formed.

The corkscrews are right or left-handed, according as the climbing plant twines to right or left.

This view seems confirmed by (*a*) the positions in which the fossil corkscrews are found, namely, on hill sides and on rocky faces: (*b*) by what happens under similar circumstances in the present day; and (*c*) by a careful examination of drawings taken from photographs of the corkscrews themselves.

Fig. 5 of Plate cxvi., p. 644, gives five specimens of the corkscrews in position.

The mode of production of the corkscrew is shown at Fig. 3, D, of Plate cxvi., p. 644.

SPIRAL CLIMBING PLANTS; REVOLVING AND TWISTING OF STEMS, TENDRILS, &c.

This heading suggests and naturally raises a question of great importance in the present inquiry, namely, can plants, and parts of plants, move, and if so, can they move in given directions, and to definite ends? Modern science unhesitatingly answers in the affirmative. A living plant moves in all its parts and particles, and the more highly differentiated, such as the climbing, sensitive, pitcher, insectivorous plants, &c., display a low form of cognition, and act as a rudimentary intelligence would dictate.[1]

The highest plants are even on a more elevated platform than the lowest animals.

The sensitive plant responds to the touch of the investigator; the pitcher plant inveigles insects into its scented, cool, but deadly chamber; Venus's fly-trap spreads its dainty leaves as the happy hunting ground for tiny living things which it seizes and devours; and the sundew baits its amazingly sensitive hairs with a glistening, viscid secretion, which attracts and ensnares large numbers of small living creatures. The sundew kills the insects and ultimately digests them by a secretion akin, in all respects, to the gastric juice of our own stomachs. It has been known to catch small butterflies and even dragon-flies. That a plant—a mere plant—should achieve such extraordinary results is difficult of realisation, but there is no disputing the facts.

Time was when it was vaguely asserted that plants were distinguished from animals by not having the power of movement.

All that is changed now; and it becomes a question, and a serious one, whether plants are not provided with a semi-fluid, diffuse, nervous system. That they are sensitive, and feel, is beyond doubt; and that their movements are purpose-like and pre-arranged is equally certain.

Plants, like animals, have a great mission to perform, and they perform it admirably and independently; that is, they are not influenced to any appreciable extent by their surroundings.

The functions performed by quite a large number of plants necessitate a nervous system or its equivalent.

That the said system has not assumed a visible form, and cannot be detected by the eye, or reagents, is no proof of its non-existence. The same may be said of all force, and of electricity in particular. Forces are only known by the effects they produce, and if plants perform many of the functions performed by animals, which are provided with rudimentary and complex nervous systems, it is reasonable to conclude that they possess a nervous system of a kind.

The argument now employed is virtually that urged in other departments of physiology. It is not possible, for example, to detect with the unaided eye, or with the assistance of the microscope, any difference in ultimate composition between the several impregnated ova: yet one ovum produces an elephant; a second, a crocodile;

[1] I recognise the difficulty and even the danger of employing the term cognition in the present connection, as it may be taken to imply understanding, perception, judgment, and even consciousness. On the other hand, reflex action, instinct, and other terms which do not convey the idea of knowing in some form, do not, it appears to me, meet the requirements of the case. Plants not only move in specific directions, but they exercise a selective power, and deport themselves generally in a way which shows that they are not mere automata. Of course there are two ways of looking at this subject. The Divine Agency or First Cause—the source of all intelligence—may be regarded as working in the plant, and directing all its movements, and superintending the discharge of all its functions; or the plant may be regarded as endowed by its Maker with peculiar powers which take the place of cognition in animals, and enable it to maintain its place in nature. What modern science has to recognise is that plants and animals, from the lowest to the highest, are capable of looking after themselves; that they are not accidental formations, with chance lives, and uncertain destinies, but things formed to achieve certain results, which they invariably do achieve, after their own peculiar fashion, and independently. It is not words we have to deal with but facts, and a term, I doubt not, will be found ere long to express *that something* in the higher plants and lower animals which makes them superior to their surroundings and enables them to work out their own destinies.

a third, a bird ; and a fourth, a man. All ova are unquestionably different *even as ova.* This goes without saying. The matter is one of pure reason.

If plants can feel, and move to definite ends (and this is now generally admitted), and if they are sensitive and respond to the touch much in the same way that animals do, there is no halting-place ; a nervous system, or its equivalent, must be predicated. If, moreover, the several kinds of plants, and the various parts of the same plant, exhibit different degrees of sensitiveness, it follows that there is differentiation in the power of feeling. The same holds true of the sensitiveness of our own bodies ; some parts are more sensitive than others.

If, finally, sensitiveness is a proof of the possession of a nervous system, then the insectivorous plants, such as the sundew, unquestionably possess it ; for as Darwin has shown, their delicate tactile hairs and glands display a degree of sensitiveness which is not approached, far less equalled, by any part of the human body. The glands of the sundew appreciate and are set in motion by a speck of human hair measuring the $\frac{8}{1000}$ of an inch in length, and weighing only the $\frac{1}{78740}$ of a grain. Moreover, "far less than the millionth of a grain of ammonia in solution, when absorbed by a gland, acts on it and induces movement."

The movements in plants greatly resemble those in animals. They occur at regular, and irregular intervals. Growing and climbing plants move irregularly according as the temperature rises or falls, and at different seasons of the year ; while certain plants, the *Volvox globator*, for example, apart from temperature, display well-marked, continuous rhythmic movements, in all respects analogous to those occurring in the heart and hollow viscera of vertebrates.

Plants, like animals, respire. The following similarities and differences are to be noted.

§ 210. Respiration of Plants and Animals.

By means of the capillaries of the lungs and integument the blood of animals is aërated, carbonic acid and other matters being given off and oxygen taken in. By means of the capillaries of the system, nutritious juices and white blood-corpuscles, also concerned in nutrition, are supplied to the tissues, and effete matters taken up. By means of its vessels, intervascular spaces and leaves, a plant is nourished, grows and breathes ; it gives off oxygen and takes in carbonic acid and other matters. It stores up starch and other compounds, and uses them as occasion demands. The plant, like the animal, may be said to breathe at every pore, by the stomata of its leaves, by the vessels, intercellular passages, and cavities of its stem and branches, and by its bark when this is green.[1] There is yet another point of resemblance between the respiration of plants and animals—the air given off by both is laden with moisture. The oxygen given off by trees and shrubs communicates to the atmosphere of the forest its peculiarly exhilarating qualities ; the carbonic acid given off by the lungs of animals producing, on the contrary, a depressing effect.

Spallanzani was the first to point out that the tissues respired. The subject has likewise been investigated by G. Liebig. M. Paul Bert ("Leçons sûr la Physiologie comparée de la Respiration": Paris, 1870) shows that the muscles of cold-blooded vertebrate animals consume, relatively to their weight, less oxygen and evolve less carbonic acid than muscles of warm-blooded animals ; also that the muscles of adult animals absorb much more oxygen and evolve more carbonic acid than those of young animals. He proves that all the tissues of the body absorb oxygen and give off carbonic acid.

Leaves have the power of absorbing carbonic acid, ammonia, water, and aqueous solutions. They give off gaseous matters, especially oxygen.

Plants, like animals, can be fed on healthy pabulum and live, but if inappropriate or poisonous food be administered they sicken or die. Deleterious gases destroy both. Both have a protoplasmic origin ; both are born, live, grow, attain maturity, and die. They give back to the inorganic kingdom the elements which they originally abstracted from it to build up their own bodies. In living and dying they administer to each others' wants and necessities. The dead vegetable, in many instances, feeds the living animal. This happens in the case of the herbivora. The dead animal, on the other hand, when it decomposes, forms manure which nourishes the plant. There is a give and take between the elements forming plants and animals, and between plants and animals themselves. Plants give off gases well fitted for the respiration of animals, and animals in turn give off the gases best suited for the respiration of plants.

[1] Some authors are of opinion that the spiral vessels and their allies are receptacles for gaseous matter formed in the course of the movement of the sap within.

In spring the vessels are found gorged with sap, but later on in the season *they usually contain air.* The intercellular passages are also filled with air. Professor Passerini, of Parma, has succeeded in showing that gases are exhaled through the stomata. He obtained his results by causing a plant to absorb a solution of sulphate of sodium, and then placing slips of paper saturated with acetate of lead to its leaves. The parts of the paper corresponding to the stomata were coloured dark, clearly showing that a reaction had taken place.

This subject has been carefully worked out by Dumas and Boussingault, and put in a condensed form in the following table :[1]—

AN ANIMAL IS	A VEGETABLE IS
An apparatus of combustion or oxidation.	An apparatus of reduction or deoxidation.
Possesses the faculty of locomotion.	Is fixed.
Burns carbon.	Reduces carbon.
„ hydrogen.	„ hydrogen.
„ ammonium.	„ ammonium.
Exhales or gives off carbonic acid.	Fixes carbonic acid.
„ water.	„ water.
„ oxide of ammonium.	„ oxide of ammonium.
„ azote.	„ azote.
Consumes oxygen.	Produces oxygen.
„ neutral azotised matters.	„ neutral azotised matters.
„ fatty matters.	„ fatty matters.
„ amylaceous matters, gum, and sugar.	„ amylaceous matters, gum, and sugar.
Produces heat.	Absorbs heat.
„ electricity.	Abstracts electricity.
Restores its elements to air and earth.	Derives its elements from air and earth.
Transforms organised into mineral matters.	Transforms mineral into organised matters.

Plants, like animals, grope about in space for substances useful to them, and in so doing they not unfrequently exert a selective and elective power. Thus the roots of trees, in stony regions, avoid the rock and insert themselves into every crevice where there is soil; the roots of trees, in exposed situations, are more developed on one side than the other; the strongest roots being found on the side of the tree from which the prevailing wind comes, in which situation they act as supporting stays. Creeping plants, like the ivy and ampelopsis, develop rootlets and suckers which enable them to adhere to vertical supports; some employ hooks for this purpose; some climb and fix themselves by throwing their petioles or leaf-stalks round supports of various kinds; others twist their stems and twine round neighbouring plants or trees; others produce sensitive tendrils, by the aid of which they seize, and are supported by, structures stronger than themselves.

All these are adaptations—means to ends.

The object to be attained in the case of the climbing plants is additional support. These plants, provided by nature with only feeble stems, seek to raise themselves from the ground and rear their branches, leaves, flowers, and fruit into the air and sunlight, which, in many cases, is no easy matter, where, as in tropical forests, there are tall trees, and a thick undergrowth of scrub.

It is a beautiful sight to behold a growing, sensitive, revolving stem or tendril circling about in space in search of a supporting structure; or a subterranean root, which, by some mischance, has become exposed to the air, doubling back in search of soil.

The several modifications of plant structures, in pursuit of a common object, all point to design, and to original, inherent, and independent powers in the plants themselves, which, it appears to me, are neither sufficiently understood nor appreciated, but which open up a long vista of profitable inquiry for future investigators.

§ 211. Growth in Plants and Animals a Leading Factor in Spiral Formations and Functions.

The nature of growth, on which form, structure, and function mainly depend, has never been properly explained. It is necessary to refer to it, and to the atoms, molecules, and cells by which it is effected, somewhat fully in discussing the spiral formations and movements of plants and animals. Growth is directly the outcome of life. It exerts a threefold power :—

(*a*) A power by which it attracts or draws into the living plants or animals the extraneous substances necessary to their production, whether gases, liquids, or solids.

(*b*) A power by which it rids the plant or animal of waste products.

(*c*) A power by which it forces plants or animals, or parts thereof, against substances which form no part of their own bodies, but which are useful to them.

Growth, while undoubtedly a vital process, is nevertheless regulated by law and subordinated to the requirements of the individual, and the functions to be discharged by it. Growth is always accompanied by an increase of substance, and the increase may occur in all directions, or in particular directions. It also (and this is important)

[1] Dumas, "Balance of Organic Nature." See also Alison on "Vital Affinity" (*Trans. Roy. Soc. Edin.*, xx. 386).

exerts a well-defined power in one or more directions. It is, in every instance, aggressive; in fact it is, primarily and essentially, a pushing power, as contradistinguished from a pulling power.

Hales ascertained that the sap rose with such force in the growing vine in spring as to counterbalance a column of mercury 38 inches in height, which is equal to 43 feet $3\frac{1}{2}$ inches of water.[1] The force exerted by the roots of growing trees, as is well known, is sufficient to drive down carefully-built stone walls, and to bend, twist, and even wrench iron stanchions from their fixings.

Carpenter[2] was of opinion that plants in growing not only availed themselves of the ponderable materials of the inorganic kingdom, but also of the imponderables, such as heat, light, electricity, chemical affinity, &c.

He states his argument as under :—

"Starting with the abstract nature of force as emanating from the Creator, we might say that this force, operating through unorganised matter, manifests itself in electricity, magnetism, light, heat, chemical affinity, and mechanical motion; but that, when directed through organised structures, it effects the operations of growth, development, chemico-vital transformation and the like.

"Plants form those organic compounds at the expense of which animal life (as well as their own) is sustained, by the decomposition of carbonic acid, water, and ammonia; and the *light*, by whose agency alone these compounds can be generated, may be considered as metamorphosed into the *chemico-vital affinity* by which their components are held together. The *heat* which plants receive, acting through their organised structures as *vital force*, serves to augment these structures to an almost unlimited extent, and thus to supply new instruments for the agency of light and for the production of organic compounds. Supposing that no animals existed to consume these organic compounds, they would all be restored to the unorganised condition by spontaneous decay, which would reproduce carbonic acid, water, and ammonia, from which they were generated. In this decay, however slow, the same amount of heat would be given off as in more rapid processes of combustion; and the faint luminosity which has been perceived in some vegetable substances in a state of eramacausis, makes it probable that the same is true of light. And though the process of decay may be prevented or modified, so that the whole or a part of the materials of vegetable structures are disposed of in other ways, yet whenever they return to the condition from which they were at first withdrawn, they not only give back to the inorganic world the materials out of which they were formed, but the light and heat to which their production was due. Thus, in making use of the stores of coal which have been prepared for his wants by the luxuriant flora of past ages, man is not only restoring to the atmosphere the carbonic acid, the water, and the ammonia, which it must have contained in the carboniferous period, but is artificially reproducing the light and heat which were then expended in the operations of vegetable growth. That the relative proportion of the light and heat thus restored should be the same as that which they originally bore to each other is by no means necessary; since each (according to Professor Grove's views) is convertible into the other. In the few cases in which *motion* is affected by the vital force of plants, this may be considered as restoring to the inorganic universe a certain measure of the force which they have derived from it, in the form of light and heat."

THE GROWTH OF SPIRAL SHELLS, HORNS, BONES, TEETH, FEATHERS, &c., IN RELATION TO SPIRAL PLANTS, BRANCHES, LEAVES, TENDRILS, FLOWERS, FRUITS, SEEDS, &c.

The great majority of shells develop spirally, and all grow by additions to their outer or peripheral margins. One of the best examples is that afforded by the nautilus (*N. pompilius*). This remarkable old-world mollusc, one of the great family of cuttle-fishes, produces a complicated spiral-chambered shell which, for grace and beauty of outline, cannot be equalled, far less surpassed. The nautilus and its shell are shown at Plate xiii., Fig. 2, A, p. 28. The shell naturally divides itself into two portions; an outer, containing the body of the nautilus, and an inner, containing the slender, spiral, vascular *siphuncle*, which extends itself through the several compartments of the shell and occupies a somewhat central position. The body of the nautilus only occupies the outer compartment of the shell, the expanded tentacles acting as a sail. The other compartments, with the exception of the siphuncle, are filled with air, by means of which the animal can raise itself to the surface of the sea, on which it occasionally floats.[3]

The nautilus, in virtue of its curious habit of forming its shell in compartments and only occupying the outer one, leaves a physical record or trail of its spiral growth which is instructive, and illustrates, in a striking manner,

[1] Hales, vol. i., p. 124.

[2] "On the Mutual Relation of Vital and Physical Forces." (*Philosophical Transactions*, 1850, p. 727.)

[3] It is not quite understood by what precise means the nautilus adjusts its specific gravity so as to make it relatively lighter or heavier than the medium it inhabits. Some are of opinion that the animal can admit into and expel from its shell, not only air but also water, the latter affording it a ready means of submerging itself.

the mode of formation of all shells. If a mesial line section of the shell such as that represented at Plate xiii., Fig. 2, A, p. 28, and in the frontispiece of the present work be examined, it will be seen that the shell has been developed from a central point which is very minute, and that the coils as well as the compartments forming the shell become larger and larger as the periphery is reached. The reason of this centrifugal growth is not far to seek. By growing outwards, the shell can be indefinitely enlarged. If it grew centripetally, or towards its centre, a period would soon arrive when further growth would be impossible. Of all known shells that of the nautilus is the most intricate and beautiful. Its main spiral is grace personified, and its dissepiments or partitions form a series of the most exquisitely graduated curves, which become smaller and smaller as the central portion of the shell is reached (Plate xvi., Fig. 8, p. 31).

In contemplating the shell of the nautilus one cannot help feeling that it is a veritable gem of design; a creation of life and growth controlled and superintended from beginning to finish. It is formed spontaneously by the animal apart from irritation and extraneous stimulation. While the sea-water and the food of the animal are necessary adjuncts of its formation, the formative power inheres in the animal itself.

I particularly direct attention to this circumstance, because all spiral shells, spiral horns, spiral teeth, spiral bones, spiral vegetable structures, &c., are similarly formed, and because not a few observers trace the spiral growth and movements of plants and animals to externalities which have practically nothing to do with either.

A fine example of a conical spiral shell with a spiral whorl and spiral columella is given at Plate xvi., Fig. 3, p. 31. Original photographs and drawings of typical spiral shells occur also at Plate xiii., Fig. 2, p. 28; and Plate xv., Fig. 1, p. 30.

Beautiful and illustrative examples of the minute, delicate shells of foraminifera are provided at Plate xiii., Fig. 1, p. 28; Plate xiv., Fig. 1 and 2, p. 29; and Plate xix., Fig. 1, p. 35.

The foraminifera have a very wide distribution in time and space. They are found in the rocks in immense numbers as fossils, and they also abound in the fresh state at the present day. They are mostly microscopic, and, in addition to great beauty of form, in many instances display the most lovely colours.

The *Challenger* expedition (Sir Wyville Thomson and others) by means of deep sea dredging brought to light a large number of species hitherto believed to be extinct. This circumstance has invested the study of the foraminifera with a new and enduring interest, as it has an important bearing on the persistence of type, a subject which, of late years, has unfortunately attracted too little attention.

The growth of spiral horns is regulated by the same laws and conditions which regulate that of spiral shells. They are predetermined structures in the sense that in the normal state they persist in developing in certain directions quite apart from every form of irritability and external stimulation. All horns are not spiral, but those which are, are not chance products. On the contrary, they are designed, and as persistent as the animals they are intended to adorn and defend. This persistence points to fundamental endowment apart from environment and every form of external condition. While the great majority of horns are curved and spiral, a few are straight and palmated. The straight and palmated horns are equally the result of growth and development in particular directions. The gemsbok affords a good example of the former; the stag, of the latter. In the straight and palmated, as in the spiral horns, there is well-marked persistency. The stag, for example, sheds its horns annually, but each successive crop of horns repeats its predecessors as regards general configuration and general plan. This remark applies to the integumentary appendages as a whole. Hairs, feathers, nails, and hoofs if plucked out invariably repeat and reproduce themselves by a process of growth; the new resembling the old structures to the most minute details. The horns of the right and left sides of the head are grown in pairs, and the one never takes the place of the other. All this means fundamental endowment in contradiction to environment, irritation, and external stimulation. Photographs and drawings of the horns of the antelope, sheep, ram, &c., are given at Plate xv., Fig. 2, p. 30; Plate xvi., Figs. 1 and 5, p. 31; Plate xviii., Fig. 2, p. 34; also Fig. 8, p. 19.

Spiral tusks and teeth (Plate xvi., Figs. 2 and 4, p. 31; Plate xvii., Fig. 2, p. 32) come under the same category as spiral shells and spiral horns. They are all the outcome of co-ordinated, directed growth in past and present time. The magnificent tusks of the extinct mastodon, measuring over seven feet in length, afford splendid examples of predetermined structures which find their representatives in the modern elephants.[1]

The tusk of the narwhal affords another fine example. Other examples are furnished by the barberi, a species

[1] The American mastodon (*Mastodon giganteum*) survived up to the late Pleistocene period. A nearly perfect specimen of it was found in Missouri in 1847 and is now in the British Museum. This specimen measures 20 feet 2 inches in length; 9 feet 6¼ inches in height; length of cranium, 3½ feet; breadth of cranium, 2 feet 11 inches; length of tusks, 7 feet 2 inches; circumference of tusks at base 27 inches.

Some of the mastodons measure as much as 12 feet at the shoulder.

The mammoth (*Elephas primigenius*), another of the great extinct family of elephants, has been found in considerable numbers in the frozen banks of rivers in Siberia. Some of these have the hair, skin, flesh, and other soft parts preserved as well as the bones; one fine specimen being deposited in the Museum at St. Petersburg. The mammoth, like the mastodon, was coeval with man on the earth. It was well known to the primitive hunters of Northern Europe, one of whom drew a picture of it on a fragment of its own tusk.

of wild pig. The tusks of the latter are beautifully curved. This is true also of the tail of the lyre bird (Plate xvii., Fig. 1, p. 32).

The curved claws of animals are essentially spiral in their nature, and the teeth of many animals display spiral peculiarities. This is true of the re-curved teeth of serpents, and, in some cases, of the under incisor teeth of rabbits. The curves of teeth and shells not unfrequently resemble each other.

Examples of spiral bones and joints abound in the so-called long bones of the body, such as the arm and hand and leg and feet bones (Plate xxi., Figs. 1 and 2, p. 37). These bones and joints are moulded by, and adapted to, the spiral muscles which actuate or set them in motion for the purposes of progression, and for the movements of the arms and legs generally.

An illustrative series of human spiral bones, carefully drawn for the present work from specimens in the Author's possession, is given at Plate xxi., p. 37. This plate also shows certain of the ball and socket and spiral hinge joints, and likewise the spiral markings or lines of insertion on the bones for the attachment of the spiral muscles.

The spirality is not confined to human bones. It is seen to perfection in the elephant and other large mammals (Plate xx., Fig. 3, p. 36).

The figure of the spiral bones of the anterior and posterior extremities of the elephant is from a photograph which I had expressly taken of the skeleton of an elephant in the Hunterian Museum of the Royal College of Surgeons of England. It is very characteristic, and brings out in strong relief, not only the spirality of the long bones, but also that of the scapulæ and pelvic bones.

In the figures illustrating spiral bones, joints, and muscles in the human subject (Plate xxi., Figs. 1 to 5, p. 37) the darts indicate the direction in which the spirals run.

While the majority of feathers are curved and convex, and overlap, a large number of them are spiral. Thus the primary feathers of the wing of the bird, especially the peripheral ones, are distinctly twisted upon themselves; the free margins being arranged in double curves in different planes, figure-of-8 fashion (Plate xvi., Fig. 6, A, B, p. 31).

The tail and other ornamental feathers of many birds are also distinctly spiral in their nature. Thus the outer tail feathers of the lyre bird, and of Wilson's bird of paradise, display the most beautiful spirals imaginable (Plate xvii., Fig. 1, A, B, p. 32).

The tails of certain animals exhibit similar peculiarities, as witness the tail of the spider monkey and that of the two-toed ant-eater. In these cases the tail is prehensile and serves the purposes of a hand.

The spiral arrangements of branches, leaves, flowers, fruits, and seeds, and the twisting of stems, tendrils, &c., afford illustrative examples of spiral growth and development in plants (Figs. 10 to 16 inclusive, pp. 20, 21; Plate ix., Figs. 1, 2, and 3, p. 22; Plate x., Figs. 1, 2, 3, and 4, p. 24; Plate xi., Figs. 1, 2, and 3, p. 25). It is not possible to refer any of the spirals to mere mechanical irritation or external stimulation.

A growing plant develops its several parts, spiral or otherwise, in a certain order and in given directions. It carries out the creative fiat with unerring precision and pertinacity, and wherever spirals are found in the parent they reappear in the offspring; their reappearance not being due to accidental circumstances, but to fundamental endowment and predetermined arrangements.

In spiral climbing plants, the stems are, for the most part, twisted or plaited (Plate x., Figs. 1 and 2, p. 24). A question has arisen as to whether spiral stems produce a spiral arrangement of branches, or whether a spiral arrangement of branches produces spiral stems. The point is immaterial, and need not be discussed. As a matter of fact, the two kinds of growth are not necessarily connected. Spiral stems generally produce a spiral arrangement of branches and leaves, but we may have spiral stems without either, and we may have a spiral arrangement of branches and leaves without spiral stems. It suffices to state that the spiral structures, wherever they occur, are spontaneous and independent, and form parts of a typical whole. There is no need to suppose that one set of spirals begets another, each set being complete in itself. It could scarcely be otherwise. Spiral structures are, in every instance, the result of spiral growth, and growth is a common attribute of all plants.

It has been stated by Mr. Darwin and also by Professor Sachs that *the supports of climbing plants produce their spirality*, and that tendrils in order to become spiral must come in contact with extraneous substances which act as irritants to them. The statement is disproved by this, that growing climbing plants continue their spiral course after they have grown above and away from their supports, and tendrils twist and develop spiral coils when not in contact with anything but the air (Plate ix., Fig. 1, p. 22).

Tendrils even develop double reversing spirals apart from contact with extraneous substances (Plate x., Figs. 1 and 2, p. 24). The existence of double reversing spirals in tendrils shows pretty conclusively that spiral growth is in no way connected with irritation and external stimulation, for if the irritation and stimulation produced a spiral twisting in one direction, they could not be credited with producing a spiral twisting in an exactly opposite direction in the same tendril; and still less when a series of reversing spirals occur in the same tendril (Plate x., Fig. 1,

p. 24). Reversing double spirals are also met with in the stems of plants, such as the hop and vegetable marrow, when not in contact with supports (Plate x., Fig. 2, B, C, p. 24, and Plate cvii., Fig. 2, p. 613).

The irritation theory of the production of reversing double spirals as advocated by Mr. Darwin and Professor Sachs is illustrated at Fig. 3 of Plate cix., p. 628. In this figure a tendril of white bryony (B) is represented as having seized a branch (A) and curved round it at x. The tendril has thus secured two fixed points, u and w. The theory is that the tendril twists in two opposite directions at v on the fixed points u and w. Against this I have to repeat that the double reversing spirals are formed in the air when the tendril does not encounter a foreign object, and when there is no second fixed point. Further, growing stems, such as the hop, develop reversing double spirals when not in contact with a hop pole, clearly showing that they are natural productions (Plate x., Fig. 2, B, C, p. 24).

The following account of the supposed origin of double reversing spirals is given by Professor Sachs: "These parts of the tendril which are between its base and the point where it is fixed are obviously not able to coil themselves around the support, although the stimulus which causes the curvature is propagated to this region; the effect of the stimulus is simply that the portion of the tendril lying between the fixed point and the rigid base becomes coiled in the form of a corkscrew, often with very numerous coils. . . . This coiling up of tendrils fixed to supports is thus, in the same sense as the twining round the support itself, an effect of irritability, and it is only the mechanical impossibility of its twining round the support which impels the part of the tendril between the support and the base to coil up in this particular way. . . . The coiling up of the fixed tendrils differs from that of those which are coiled up spontaneously; for in the latter all the coils of the spiral run evenly in one direction, whereas in the turns of the spiral of a tendril fixed to a support there are points where the direction is reversed, between each two of which there always lie a number of turns in the same direction, which is opposite to that of those between the next such points. In long closely-wound tendrils there are often five or six points of reversal. Darwin has already pointed out that this is not a peculiarity confined to tendrils, and still less a specific consequence of the stimulus; on the contrary, the occurrence of points of reversal is a mechanical necessity. If a body which tends to coil up is fixed at both ends so that neither end can twist round, coils in opposite directions must of necessity occur, in order to compensate for the torsion inseparable from the coiling up."[1] The following are the statements made by Mr. Darwin on this important subject: "When an uncaught tendril contracts spirally, the spire always runs in the same direction from tip to base. A tendril, on the other hand, which has caught a support by its extremity, invariably becomes twisted in one part in one direction, and in another part in the opposite direction; the oppositely turned spires being separated by short straight portions. . . . It occurs without exception with all tendrils which after catching any object contract spirally, but is of course most conspicuous in the longer tendrils; it never occurs with uncaught tendrils. . . . Commonly all the spires at one end of a caught tendril run in one direction, and all those at the other end in the opposite direction, with a single, short, straight portion in the middle; but I have seen a tendril with the spires alternately turning five times in opposite directions, with straight portions between them. Whether the spires turn several times in opposite directions, or only once, there are as many turns in the one direction as in the other."[2]

With reference to the last passage in the above quotation from Mr. Darwin, I have to remark that it varies in several points from Fig. 13 of his paper to the Linnæan Society.

In the illustration in question the turns forming the reversing spiral are not equal in number. On the contrary, three turns run in one direction, six in another direction, and two in the same direction as the first three.

The passage is also at variance with my observations and illustrations (Plate cvii., Fig. 2, *d*, *e*, *f*, of C, p. 613; Plate cviii., Figs. A, B, C, p. 618.

While Mr. Darwin's torsion theory is true where a dead vegetable or other fibre is fixed at both ends and twisted in the middle between the finger and thumb, it is not true when the fibre is fixed at one end only and the torsion applied at the other end; neither is it true in the living, growing tendril, which, in many cases, is only fixed at one end, namely, the base of the tendril, but which, as I have explained, nevertheless develops not one double reversing spiral, but several, as shown at Plate cxvi., Fig. 2, A, B, p. 644. If double reversing spirals can be thus formed in the air, and with only one fixed point, it follows that they are a natural product, and in no way due to fixation, torsion, irritability, or external stimulation, as Mr. Darwin and Professor Sachs state. This matter can readily be settled by experiment.[3] If a flat ribbon of vegetable fibre or india-rubber be fixed at both ends and torsion applied in the middle, two opposite spirals are at once formed (see Fig. B of Plate cviii., p. 618). If the ribbon be only

[1] "Lectures on the Physiology of Plants," by Julius von Sachs; translated by H. Marshall Ward, M.A., F.L.S., &c. Oxford, 1887, pp. 662, 663, and 664.

[2] "On the Movements and Habits of Climbing Plants," by Charles Darwin, Esq., F.R.S., F.L.S., &c. Extracted (with illustration 13) from the *Journal of the Linnæan Society*, London, 1865, pp. 95, 96.

[3] Experiments on this and cognate subjects by the Author are described and figured at Plate cviii., p. 618.

fixed at one end and torsion applied to the other end, only one spiral is produced. The torsion at the one end may be continued until the spiral overruns or loops, but whatever the degree of torsion, the spiral always remains single and runs in one direction. It never reverses or becomes double and runs in two directions (Plate cviii., Fig. D, p. 618).

The artificially produced spirals do not explain those occurring in growing tendrils and stems. To produce a double or reversing spiral artificially both ends of the ribbon must be fixed and the torsion applied at the centre of the ribbon (Plate cviii., Fig. B, p. 618). In the case of the growing tendril and stem very frequently only one end is fixed, namely, that at the base or root; the other end being quite free and only in contact with air. Nevertheless, under these circumstances, nature can and does produce single spirals running in one direction, and double or reversing spirals running in two or opposite directions.

This interesting subject has already been discussed in another part of the work (" Sensitive Moving Plants, Spiral Climbing Plants, Revolving and Twisting Stems, Tendrils, Leaves," &c., p. 605).

The mechanical theory of their origin is clearly untenable, and must be abandoned.

The power of plants to circumnutate and twine round objects, and make single right and left-handed spirals and double reversing spirals, is plainly an original, that is, a fundamental endowment; and, as such, is indicative of design, and design of a high order. Climbing plants, by means of their revolving apex shoots, feel about in all directions like intelligent beings until they find suitable supports. If baffled in their pursuit, they do not give up their twisting, coiling, spiral movements, which are inherent.

Spirals of various forms are likewise produced by the rays of certain star-fishes when not in contact with anything but water. When, however, they do happen to encounter and twist round extraneous substances the twisting frequently does not occur at the tip (the point of contact), but at the root of the rays, showing that the spirality is inherent. In such cases, the amount of spirality is altogether in excess of the degree of stimulation (Plate xx., Fig. 1). Similar remarks are to be made of *Clematis glandulosa*. Moreover, the egg-cases of sharks and dog-fishes develop spiral processes or tendrils while floating in the water, and before they anchor themselves to foreign support of any kind (Plate xviii., Fig. 1, A, B, C, p. 34).

Spiral seeds, spiral fruits, spiral leaves, branches, stems, and other parts of plants are spontaneous fundamental structures in no way due to irritability, or to extraneous stimulation; and, as already stated, the same is true of spiral teeth, claws, horns, muscles, bones, and other parts of animals.

The obvious inference is that spiral growth is neither occasioned nor controlled by the growing thing coming in contact with external objects; it being in every case the outcome of original endowment and design. The spiral structures in climbing plants are specially formed for seizing and for availing themselves of supports, but if the supports are not forthcoming the spiral growth goes on in their absence. The supports are to spiral climbing plants their natural objectives, just as light, and what it reveals, is the natural objective of the eye, sound and sounding bodies of the ear, sapid substances of the palate, &c. The spiral structures are conditioned; they are means to ends.

Similarly, the spiral teeth, claws, horns, muscles, bones, and joints have all their uses. The teeth and claws seize and lacerate; the horns attack and defend; the muscles, bones, and joints contribute to the spiral, sinuous, figure-of-8 movements by which animals progress, whether in walking, swimming, or flying; these movements being necessary to secure food, and for the ordinary purposes of life.

§ 212. The Prevalence of Spiral Formations: their Physiological Significance in Relation to Walking, Swimming, and Flying: the double figure-of-8 Curves and Spirals made by the Wings in Flight not known to Leonardo da Vinci.

The universality of the spiral in nature is a subject alike for surprise and reflection. As regards beauty of outline, the spiral transcends all other forms, and is invariably a source of pleasure. The spiral occurs very frequently both in the inorganic and organic kingdoms, and, as I hope to show in the present work, has its own special uses. It is seen, as already stated, on a grand scale in the spiral arrangements of nebulæ, in the whirlwind and whirlpool, in the waterspout and sand-storm, in the cyclone and other natural phenomena.

As regards living things it is fundamental, and, as explained, manifests itself in the most rudimentary plants and animals, in the cells and seeds of the higher plants, and the spermatozoids of the more complex animals. It makes its appearance, so to speak, at the very threshold of life, and can be traced through the whole vegetable and animal kingdom up to man himself. It is seen, as has been pointed out, in spiral stems, spiral tendrils, spiral leaves, spiral flowers, spiral fruits, &c., in plants; and in spiral feathers, spiral shells, spiral horns, spiral teeth, spiral bones, joints, and muscles in animals. It not only abounds in every department of plant life, but it also lends itself freely to

the construction of nearly every kind of external and internal skeleton of animals. All the hard and soft parts of animals are, with few exceptions, dominated by it. It is a thing not of accident, but of design.

Apart from the beauty and grace which inheres in every variety of spiral, I think I can trace in it a hidden and far-reaching purpose. Indeed I can show that not only do spirals enter largely into the formation of plants and animals, but also that the complicated movements of climbing plants and tendrils, and of walking, swimming, and flying, are directly traceable to their existence: nay more, that the circulation of the blood in birds and mammals is, in great measure, due to the ventricles of the heart being composed of powerful combinations of spiral muscular fibres. As a matter of fact, the blood in birds and mammals is forced by the ventricles into the larger blood-vessels (especially the aorta) by spiral movements which cause it to gyrate within them much in the same way that a rifle bullet is made to gyrate within a rifle, when the weapon is discharged. The ancient and grim phrase "wringing the heart's blood" has, curiously enough, its foundation in fact.

The spiral ventricles of the heart in birds and mammals are typical of many other structures. Thus in man the stomach, bladder, uterus, &c., are all composed of spiral, figure-of-8, muscular fibres, and, strange as it may appear, the food, the urine, and even the fœtus, are subjected to spiral pressure when being passed on and extruded. In parturition, in the human female, the progeny makes a distinctly spiral exit; a result produced partly by the movements of the uterus and partly by the configuration of the pelvis.

The spiral pressure in the case of the ventricles of the heart and of the stomach is due to the fact that these structures are composed almost wholly of spiral, figure-of-8, muscular fibres, and are twisted upon themselves automatically. In the case of the bladder and uterus the twist is less marked, but as they likewise are composed of spiral, figure-of-8, muscular fibres, it follows that the slightest excess of muscular action on either side of the mesial line results in spiral movements.

The spiral, figure-of-8, muscular fibres of the ventricles, stomach, bladder, and uterus cross at ever increasing and decreasing degrees of obliquity, according as the central layers are approached or departed from; an arrangement which results in a maximum of strength with a minimum of material. These viscera are constructed on the girder bridge principle, where the strain is diffused throughout the entire structure by a system of lattice trusses disposed at various angles. A modification of the arrangement in question appears in the muscles of the thorax and abdomen; in the muscular masses which invest universal or ball and socket joints; in the muscles of the diaphragm; in the fasciæ, the aponeuroses, the ligaments, and indeed wherever unusual strength is required.

The individual fibres of certain muscles tend to cross at various degrees of obliquity, and hence the several examples of simple and compound penniform muscles.

The heart is at once the most spiral and powerful muscle in the body, if the amount of work performed by it and its unceasing activity be taken into account. The ventricles of the heart are also by far the most complicated muscles known. Their arrangement forms a veritable Gordian knot in anatomy. The famous anatomists, Vesalius, Albinus, Haller, and De Blainville, all confessed their inability to unravel it.

The ventricles of the heart are deserving of very particular attention, both as regards their structure and function, from the fact that they throw a flood of light on muscular arrangements and movements as a whole.

The ventricles, stomach, bladder, and uterus are bi-laterally symmetrical, and in this respect resemble the other parts of the body.[1] There is, moreover, a tendency on the part of bi-lateral organs to overlap and display greater activity on the one side than on the other.

Additional examples of spiral structures in animals may be given. The alimentary canal, as a whole, is more or less spiral. The vermiform appendix is particularly so. The turbinated bones of the nostrils, the ducts of the sweat glands, the *tubuli uriniferi*, the spermatozoa, the touch corpuscles, the convolutions and other parts of the brain, the umbilical cord, &c., are all distinctly spiral. The cochlea of the human ear forms a spiral, which, for symmetry and beauty of form, will compare, not unfavourably, with the wonderful spiral shell of the nautilus, regarded by conchologists as the *facile princeps* of its kind. Nor is the list by any means exhausted. The nerves in many cases are spirally arranged. They are so arranged in the heart of the bird and mammal; in the cochlea of the human ear; in the nerve end bulbs, where sensation is most exalted. Perhaps the best examples of spiral nerve distributions are to be seen in the ganglion nerve-cells of the frog, where the most extraordinary single and double spirals are encountered. Spiral arrangements are also to be traced in areolar tissue when treated with acetic acid. In such cases the elastic fibres are observed to wind round bundles of white fibres. The *ligamentum nuchæ* in man and animals consists of a mass of yellow elastic fibres, and, when these are teased out with needles and examined under the microscope, their free extremities curl and twist in quite a remarkable manner. Last, and certainly not least, there are, as already indicated, spiral bones, spiral joints, and spiral muscles, both voluntary and involuntary.

[1] Generally speaking, the symmetry in plants and animals is produced by their component parts, consisting of two or more spirals, starting a different points and overlapping symmetrically at their terminal portions.

Outstanding examples of spiral bones are met with in the anterior and posterior extremities of bipeds and quadrupeds. The humerus, radius, ulna, metacarpal and phalangeal bones of the anterior extremities, and the femur, tibia, fibula, metatarsal and phalangeal bones of the posterior extremities, are unmistakably spiral in their nature, and this spirality extends to the origins and insertions of the voluntary muscles which actuate and set these bones in motion. It extends also to the muscles themselves, which in many cases are arranged in spiral lines round spiral cavities and spiral bones and joints, and produce spiral movements observed in the heart and its valves and in the extremities and other parts of the body. Spiral movements are particularly well seen in the anterior and posterior extremities of bipeds and quadrupeds in walking; in the tails and fins of fishes in swimming; and in the wings of insects, birds, and bats in flying. In the case of the human fore-arm, the radius bearing the hand can be made to twist round the ulna so as to admit of pronation and supination of the hand. Similar remarks are to be made of the arm and fore-arm or wing of the bird, with its modified wrist and hand bones and wonderful arrangement of feathers, by the aid of which the bird can screw its wing into and seize the air during the down stroke, and unscrew and withdraw it from the air during the up stroke. Good examples of spiral joints are found in the elbows and knees of birds and mammals. Similar but slightly modified joints are met with in the bones of the hands and feet.

All muscles, voluntary and involuntary, are, fundamentally and as a whole, spiral in their nature. Sometimes only a curve or portion of a spiral can be distinguished: at other times entire systems of double reversing spirals can be made out.

The involuntary muscular fibres of the ventricles of the heart in the bird and mammal, and in the bladder and uterus of the human female, afford beautiful examples of complicated double spirals; and one has only to study the spiral configuration of the bones (especially the long bones) as seen in the extremities of birds and mammals, and the spiral configuration of the joints connected therewith, to be convinced that the voluntary muscles must not only be spirally arranged, but that they must also act spirally.

The spiral action of the voluntary muscles is most observable where they act upon spiral joints, but it is also well seen where they act upon universal or ball and socket joints, such as the shoulder and hip joints. It is in virtue of the spiral action of the muscular masses connected with ball and socket, and with spiral, hinge, and other joints, that circumduction and partial rotation of the arms and legs are possible. It is a curious fact, that the muscular masses which invest and actuate ball and socket joints have their fibres arranged very much as the muscular fibres of the ventricles of the heart in birds and mammals are arranged; that is, they run in vertical, oblique, and transverse spiral directions. The muscles of the pharynx, œsophagus, and tongue follow the same general plan. In the case of Venus's flower-basket (*Euplectella aspergillum*), the hard parts forming the skeleton carry out the spiral design in a remarkable and striking manner. The distribution of the muscles round ball and socket joints, and the arrangement of their fibres, find their counterpart in the diaphragm, which may be considered a universal muscle. In the diaphragm, the muscular fibres run longitudinally, transversely, and at every degree of obliquity, as in the ventricles of the heart, stomach, bladder, and uterus. The diaphragm fitly represents a half of either of the viscera named, and like them, is endowed with independent movements.

The voluntary and involuntary muscles, it will be seen, are arranged in spiral cycles; the only difference between the two kinds of muscles being that in certain of the hollow viscera, say the ventricles of the heart of the bird and mammal, the involuntary muscles are arranged round *spiral cavities*, whereas the voluntary muscles, say those occurring in the extremities of the bird and mammal, are arranged round *spiral bones and spiral and other joints*.

The involuntary hollow muscles communicate, as stated, a spiral impulse to the substances contained within them; the voluntary solid muscles, on the other hand, cause the extremities and other parts of the body to make spiral movements and describe spiral trajectories.

While the spiral cycles formed by the voluntary muscles are best seen in the anterior and posterior extremities of bipeds and quadrupeds, they are also well marked in the chest, abdomen, neck, and other parts of the body. Single muscles rarely act by themselves. Muscles, as a rule, act in combination, and their movements, which are co-ordinated and complementary, extend in spiral waves to the bones, joints, and other parts to be set in motion; hence those wonderful muscular movements and adaptations which we behold in walking, swimming, and flying.

Muscles, whether voluntary or involuntary, in every instance act harmoniously and to given ends. Their movements are never perfunctory or haphazard. There is no such thing as flexor muscles forcibly and violently dragging out extensors, pronators, supinators, abductors, adductors, and the converse. This would be a mere waste of power, as it would necessitate one muscle contending with another, while each muscle has the same object in view, namely, the moving of certain bones or parts. When the flexor muscles shorten or contract, the extensor muscles elongate or relax. This they do by simultaneous centripetal and centrifugal movements. Not only do the voluntary muscles act together and in groups, but they require to be trained to prevent antagonistic action. Walking, swimming,

and flying have all to be learned, and the training consists in teaching the several muscles, and groups of muscles, to act in concert at stated intervals. Antagonism in muscular action would be fatal to the performance of muscular work. As a matter of fact, all muscles are invested with a double vital power, whereby they can shorten and elongate, or, what is the same thing, close and open by alternate centripetal and centrifugal movements, the flexor muscles closing and shortening, when the extensor muscles open and elongate, and *vice versâ*.

In no part of the body do curves and spirals play a more prominent part than in the spinal column, and at the shoulders and pelvis. In man, the spinal column consists of four exquisite curves; the convexities of the cervical and abdominal curves being directed forwards, the convexities of the thoracic and pelvic curves being directed backwards. This double system of curves diffuses shocks equally from above and below, and presents a line of beauty not matched even by that of the famous limner, Hogarth. In addition to the antero-posterior curves, the spinal column reveals lateral curves which become prominent in certain diseases of the spine. The antero-posterior and lateral curves referred to confer great elasticity and freedom of movement; a state of matters intensified by the large number of vertebral ligaments and intervertebral cartilages. In virtue of its curves, freedom of movement, and structural peculiarities, the spinal column can, to a slight extent, rotate on its own axis in the direction of its length. The rotatory movement is seen to advantage in the swimming of fishes, where the tail alternately presents flat and oblique surfaces which enable the animal to seize or let go the water in the act of propulsion. The spinal column is characterised by antero-posterior, lateral, curved, spiral, and semi-rotatory movements. It is endowed, practically, with universality of motion. Nor will this occasion surprise when it is remembered that it constitutes the centre of the trunk and the axis of the body. Even the skull is a part of it.

The various movements of the spine are transferred by screwing, twisting, and partial rotatory movements at the shoulders and hip-joints to the upper and lower extremities, or their representatives (fins, flippers, and wings) when they exist. The extremities, and all modifications thereof, inherit, as was to be expected, the fundamental movements of the spine.

The pelvis consists of a series of most beautiful arches (some of them skew), and the bones composing the arches are twisted in various directions. Similar remarks apply to the scapulæ forming the shoulder joints, the clavicles, and the ribs.

The bones of the extremities, as already pointed out, are spiral in their nature, but they are also, in the majority of cases, slightly bent in the direction of their length; a circumstance which contributes greatly alike to their elasticity and their strength. Additional strength and elasticity are obtained in the case of the arm and thigh bones (humerus and femur) by the bones being provided with short, oblique necks where they articulate with the body; an arrangement calculated to neutralise impacts of all kinds from the hands, feet, and other parts of the extremities.

The cartilages of bones, especially the intervertebral cartilages, act as buffers, and play a most important part in the diffusion of shock. Nowhere is this seen to greater advantage than in the springy vertebral column, which enables individuals to take high leaps and carry great weights on their heads without producing concussion and injury to the delicate semi-fluid brain and spinal cord. If sudden and great pressure be applied to the head, the shock is transmitted from above downwards; the last parts affected before it reaches the ground being the beautiful double arches (longitudinal and transverse) of the feet.

In virtue of the spiral arrangements which obtain in the muscles, and in the bones and joints of the extremities, the limbs of bipeds and quadrupeds in walking and running describe alternating, complemental, figure-of-8 curves arranged in different planes, which approximate but never interlock. A locking movement of the extremities would render locomotion impossible. It follows that men and animals can, by the aid of their extremities, which move in free spiral curves, perform long journeys without difficulty.

As is well known, the bodies of vertebrate animals are bi-laterally symmetrical. This is especially true of man, who may be regarded as the paragon of living forms. In order to bring about this bi-lateral symmetry, the body is composed of right and left-handed spiral segments; the one slightly overlapping and dominating the other. This view is favoured by the fact that antelopes and other animals which grow spiral horns invariably produce a right-handed spiral on one side of the head and a left-handed spiral on the other or opposite side of the head. The overlapping, stronger, and more active segment practically settles the question of right and left-handedness; the individual being right-handed when the right segment, and left-handed when the left segment, is in the ascendant. The brain as the controlling agent is a leading factor in determining whether an individual is to be right or left-handed. Some there are who, ignoring the teachings of anatomy and physiology, maintain that a child becomes right or left-handed according as the right or left hand is left most free during the nursing period when the child is in arms. This theory fails to explain the fact that right and left-handedness, like strabismus, runs in families. Right and left-handedness, moreover, continues notwithstanding the employment, in recent times, of children's perambulators, where the hands of infants are left equally free, and where nurses can exert no influence one way or

other. Without entering into the subject too minutely, it is safe to assert that one side of the body is almost invariably stronger than the other, and that this greater strength, however produced, inclines the individual to use that side, and the extremities of that side, the most. This is well seen in the lead taken by one or other extremity in walking. If the eyes be blindfolded it is not possible to walk in a perfectly straight line. It is found, moreover, next to impossible to walk in a perfectly straight line even when the eyes are open and fixed on a given object. Unconsciously, the heavier, stronger, and more active half of the body asserts itself, and the individual swerves in curves to the right or left in spite of himself. The curved spiral movements of the limbs, and the trend to the right or left in particular instances, explain why natural footpaths in fields and waste places are almost invariably tortuous and winding.

The spiral arrangements to which reference has been made culminate in the movements of walking, swimming, and flying. These important movements, on which the lives of the higher animals largely depend, are, as I showed in 1867 and subsequently, distinctly spiral in their nature.[1]

When a man walks he twists his body at the shoulders and hips diagonally; the right arm and left leg advancing together to form one step; the left arm and right leg advancing together to form a second step; the right arm and left leg in walking make opposite spiral curves, and these are crossed by similar curves made by the left arm and right leg; the result being a series of double, figure-of-8 curves.

The same thing happens when a bird swims by the aid of its feet. In this case the right leg with the right webbed foot fully expanded, is, during the effective stroke, thrust in a backward direction and makes a right-handed curve; the right foot, which during the non-effective stroke is closed and drawn towards the body, making a left-handed curve. The left leg and foot perform similar movements, and as the right and left legs and feet act alternately, double, or figure-of-8 curves are generated. Similar remarks are to be made of the movements of quadrupeds. These, however, are slightly more complicated. Thus in the walk of the horse the body is alternately supported on diagonals formed by the right fore and left hind legs and the converse; on laterals formed by the right fore and right hind legs and the converse; and on tripods formed by the two fore legs and one hind leg and the converse. In one stride the body is successively supported, (*a*) by the two hind legs and the left fore leg; (*b*) by the left fore and right hind legs; (*c*) by the two fore and right hind legs; (*d*) by the right fore and right hind legs; (*e*) by the right fore and the two hind legs; (*f*) by the right fore and left hind legs; (*g*) by the two fore and left hind legs; and (*h*) by the left fore and left hind legs.

The supports formed by the legs of the horse vary in the several paces, such as the trot, the gallop, the amble, &c.

The outstanding feature in all the paces is the twisting movements of the body at the shoulders and hips and the sinuous, double, figure-of-8 curves made by the legs and feet on leaving and reaching the ground. These double curved movements are well seen in the swimming of the fish, especially the long-bodied fishes. In swimming, the body of the fish is thrown into alternating, complemental, cephalic, and caudal curves. Generally the sinuous double-curve movements can be traced also in the pectoral fins of fishes; these fins being the homologues of the anterior extremities of quadrupeds and bipeds. They invariably occur in the tail, which is lashed from side to side by a sculling movement. The tail of the fish is made to vibrate laterally, and while so engaged it twists upon its root or long axis in such a manner as to produce double curve, figure-of-8 movements. The pectoral and caudal fins of fishes are of a generally triangular shape, and are beautifully graduated, tapering elastic structures. They closely resemble wings both in structure and function. They are all propelling organs. If the pectoral fin of the thresher shark (*Carcharias vulpes*) be examined, it will be found that it is triangular-shaped, thick, and semi-rigid at the root and along the anterior margin, and thin and elastic at the tip and along the posterior margin. This is the type of all wings, as an inspection of the wing of an insect, bird, or bat will show. Wings are slightly twisted upon themselves structurally, and are screws functionally. The main difference between the pectoral fins of the shark and the wings of flying creatures consists in the greatly increased size of the latter. In only one case, namely, that of the flying fish, do the pectoral fins approach the wings of the bird and bat in dimensions. The flippers of the dolphin, whale, and sea bear resemble the pectoral fins of the shark both in form and function. The fins and tails of fishes and the flippers of sea mammals simply propel. The wings of insects, birds, and bats propel, elevate, and sustain. Fins, wings, and flippers, however, act on a common principle, which finds its expression in the sinuous, double curve, figure-of-8 movements referred to in the walking of the quadruped and biped and in the swimming of the bird and fish. That wings act as explained can readily be verified by holding a bluebottle fly or a bee against a dark background in a strong light when the wings are vibrating rapidly. The blur or impression produced on the eye of the spectator by the swiftly moving wing is twisted figure-of-8 fashion; a circumstance due to a change

[1] "On the Various Modes of Flight in Relation to Aeronautics" (*Proc. Roy. Instit. Great Britain*, 1867); "On the Mechanical Appliances by which Flight is attained in the Animal Kingdom" (*Trans. Linn. Soc.*, vol. xxvi. 1867); "On the Physiology of Wings" (*Trans. Roy. Soc. Edin.*, vol. xxvi. 1870); "On Animal Locomotion" (Anglo-American Science Series, 1873), &c.

of plane in the wing and to the fact that the wing acts spirally in two directions as it hastens to and fro; the double curves forming one half of the 8 being developed during the forward stroke, and the double curves forming the other half of the 8 being developed during the back or return stroke. In free flight the figure-of-8 is opened out spirally, the wing in this case making a waved trajectory in space. In the insect the wing acts more horizontally than in the bird and bat. In the bird and bat the spiral figure-of-8 movements made by the wings can be readily detected by a practised eye and careful observation. When the wings of the bird and bat are made to vibrate in captive or slow flight, the tips of the wings make more or less vertical figure-of-8 trajectories. In free rapid flight the figures-of-8 made by the wings are opened out and spirally unravelled and form waved trajectories as in insects. To this there is no exception, as I have very fully convinced myself alike by observation and experiment. In birds and bats the wings are more or less folded and shortened during the up strokes, and expanded and lengthened during the down strokes. The wings of birds and bats, as I first pointed out in 1867, strike downwards and *forwards* during the down stroke, and upwards and *forwards* during the up stroke. This view, wholly opposed to prevailing beliefs, was much debated at the time, but has been strikingly and amply corroborated by instantaneous photographs of flying birds taken by Mr. E. Muybridge and others. In the photographs—those of the pigeon, for example—the tips of the wings at the *beginning* of the down stroke are as far back as the extremity of the tail; whereas, at the *end* of the down stroke they are in advance of the beak of the bird the whole length of the body or more. The old idea was that the wings *pushed* the body of the flying creature forward; in reality the wings always fly in advance of the body and *pull* it forward. The result is the same, but the *modus operandi* is wholly different.

In all natural wings, and in all artificial wings properly constructed, the figure-of-8 and waved movements are invariably developed in captive and free flight. The great interest taken in artificial flight of late years invests the subject of flight with a new zest, and this has been heightened by the recent publication (1903) of a small work by Mr. Theodore Andrea Cook, M.A., entitled "Spirals in Nature and Art: A Study of Spiral Formations based on the Manuscripts of Leonardo da Vinci, with special reference to the Architecture of the Open Staircase at Blois, in Touraine."

Mr. Cook in the work in question has attributed, rightly or wrongly, to that celebrated artist, architect, and engineer a large number of the most important discoveries of modern times. I say rightly or wrongly, as Mr. Cook adduces no proof to show that Leonardo actually made the discoveries which he has assigned to him; proofs, it appears to me, being required in the case of a *savant* who died several centuries ago, and whose writings are very little known. In the matter of flight the claims which Mr. Cook makes for Leonardo are wholly unwarranted—indeed wholly opposed to facts. Thus at pages 153 and 154 of his book he says: "The downward stroke of a bird's wing, which is supposed to be so new a revelation of the instantaneous camera, was noted independently by Leonardo. He observed, too, that as the tips of a bird's wings in flight go up and down as well as onwards, they make a spiral in the air which is adapted to the strength of wind-resistance it has to encounter; and he made use of this observation in his theory of flying machines. His brain was able to infer what no human eye could really see, and when he noted that the spiral formation of a screw was suggested by the movement of a flying bird, it was not till four hundred years afterwards that the truth of the inference could be visibly demonstrated." To make matters worse, Mr. Cook in support of the unjust claim which he sets up for Leonardo appropriates (*vide* Fig. 45 of his book) two of my original figures, which he assigns to Leonardo, without acknowledgment. In this connection I have to state that Mr. Cook in a recent issue of *Nature* (July 30, 1903) has frankly admitted that he inadvertently appropriated my figures. In his apology, however, he avers that my figures are of very little importance to his argument. He gives with the one hand and takes with the other, and in so doing repeats and adheres to a serious misrepresentation. The statement quoted above, which Mr. Cook has put into Leonardo's mouth and not withdrawn, is altogether inaccurate and misleading, and is not justified, even indirectly, by any passage or drawing occurring in the manuscripts of Leonardo da Vinci, which I have carefully examined. As a matter of fact, Mr. Cook in his great admiration of Leonardo unwittingly reads into Leonardo's short treatise and notes on natural and artificial flight the discoveries on these subjects of the last forty years. He gives to Leonardo and the sixteenth century what unquestionably belongs to me and the nineteenth century. Leonardo's chief work on flight, bearing the title "Codice sul vòlo degli uccelli e varie altre materie," written in 1505, consists of a short manuscript of twenty-seven small quarto pages, with simple sketch illustrations interspersed in the text. In addition, he makes occasional references to flight in his other manuscripts, which are also illustrated. In none of Leonardo's manuscripts, however, and in none of his figures, is the slightest hint given of his having any knowledge of the spiral movements made by the wing in flight, or of the spiral structure of the wing itself. Mr. Cook, as explained, also claims that Leonardo knew the direction of the stroke of the wing as revealed by recent researches and proved by modern instantaneous photography. As a matter of fact, Leonardo gives a wholly inaccurate account of the direction of the stroke of the wing. He states that the wing during the down stroke strikes downwards and *backwards*,

whereas in reality, and as demonstrated by me in 1867, it strikes downwards and *forwards*. In speaking of artificial flight Leonardo says, "The wings have to row downwards and backwards to support the machine on high, so that it moves forward." In speaking of natural flight he remarks, "If in its descent the bird rows backwards with its wings the bird will move rapidly; this happens because the wings strike the air, which successively runs behind the bird to fill the void whence it comes." There is nothing in Leonardo's writings to show that he knew either the anatomy or physiology of the wing in the modern sense. He certainly did not know that the wing is a screw structurally and functionally; that in captive flight it makes a figure-of-8 track; that in free flight the figure-of-8 is opened out to form first a spiral and then a waved trajectory; and that it strikes downwards and *forwards*, during the down stroke; the wings pulling and not *pushing* the bird, as Leonardo and all those who followed him believed.[1]

THE ORIGIN OF SPECIES—VARIOUS VIEWS

The origin of species, worked out with infinite industry and consummate skill by Mr. Charles Darwin, is not an absolutely new doctrine.

It may be traced back to the days of Aristotle.

Buffon, in modern times, was the first to treat the origin of species in a scientific spirit. He, however, did not deal with the causes which produce or the nature of the transformations of species.

Lamarck strongly directed attention to the subject in 1801, 1809,[2] and 1815.[3] He maintained that all species, man included, are descended from other species. He regarded the several changes in the organic and inorganic kingdoms as the products of law and not of miraculous interposition. Lamarck dilated upon the difficulty of distinguishing between species and varieties, and showed how forms are graduated and run into each other, especially under domestication. The modifications, in his opinion, were due partly to the physical conditions of life, partly to the crossing of existing forms, and much to use and disuse as the result of habit. To the latter he attributed many of the beautiful adaptations in nature. He also believed in progressive development and evolution, beliefs which induced him to adopt spontaneous generation as a means of explaining the presence of rudimentary structures in the universe.

Dr. Erasmus Darwin, curiously enough, anticipated Lamarck in several of his inductions in his "Zoonomia,"[4] published in 1794. Goethe likewise preceded Lamarck in a work written in 1794–5, and published long afterwards. Similar remarks are to be made of Geoffroy Saint Hilaire. As a matter of fact, Dr. Darwin in England, Goethe in Germany, and Geoffroy Saint Hilaire in France, arrived at similar conclusions as regards the origin of species in the years 1794 and 1795.

Geoffroy Saint Hilaire in 1795 suspected that what we call species are various degenerations of the same type.

The Rev. W. Herbert in 1822[5] and in 1837[6] asserted that "horticultural experiments have established, beyond the possibility of refutation, that botanical species are only a higher and more permanent class of varieties." He applied the same argument to animals, and expressed his belief "that single species of each genus were created in an originally highly plastic condition, and that these have produced, chiefly by intercrossing, but likewise by variation, all our existing species."

Mr. Patrick Matthew, in his work on "Naval Timber and Arboriculture," published in 1831, expressed views nearly coinciding with those of Mr. Charles Darwin and Mr. A. Russel Wallace. Darwin and Wallace gave their exposition of the origin of species in the *Journal of the Linnæan Society*, in 1858. Mr. Matthew attaches much importance to the direct action of the conditions of life, and believes that the world was nearly depopulated at successive periods and re-stocked. As an alternative he thinks new forms may be produced "without the presence of any mould or germ of former aggregates."

The author of "The Vestiges of Creation," in the tenth edition of his work (1853), originally published in 1844, thus expresses himself: "The proposition determined on after much consideration is, that the several series of animated beings, from the simplest and oldest up to the highest and most recent, are, under the provisions of God, the results *first*, of an impulse which has been imparted to the forms of life, advancing them, in definite times, by generation, through grades of organisation terminating in the highest dicotyledons and vertebrates, these grades being few in number, and generally marked by intervals of organic character, which we find to be a practical difficulty in ascertaining affinities; *second*, of another impulse connected with the vital force, tending, in the course of generations, to modify organic structures in accordance with external circumstances, as food, the nature of the habitat, and the meteoric agencies, these being the 'adaptations' of the natural theologian."

[1] An epitome of Leonardo da Vinci's views regarding natural and artificial flight is given in Appendix III.
[2] "Philosophie Zoologique."
[3] "Hist. Nat. des Animaux sans Vertèbres."
[4] Vol. i., pp. 500-510.
[5] "Horticultural Transactions."
[6] "Amaryllidaceæ."

The celebrated comparative anatomist, Professor Richard Owen, approached the subject of the origin of species with extreme caution.

Thus in his work "On the Nature of Limbs," published in 1849, he says: "The archetypal idea was manifested in the flesh, under diverse modifications, upon this planet, long prior to the existence of those animal species that actually exemplify it. To what natural laws or secondary causes the orderly succession and progression of such organic phenomena may have been committed, we, as yet, are ignorant." In his British Association Address in 1858 he refers to the "continuous operation of creative power, or of the ordained becoming of living things." Then in connection with geographical distribution he observes, that the presence of the red grouse exclusively in Great Britain is due to a "great first creative cause," and that the British Isles are as readily accounted for as the birds.

Unger (botanist and palæontologist) in 1852 declared his belief that species underwent development and modification, and Dr. Alton in his work "On Fossil Sloths" took a similar view. Oken expressed himself in like terms in his "Natur-Philosophie," and Burdach, Bury St. Vincent, Poeret, and Fries were all of opinion that new species are continually being formed.

Dr. Schaffhausen in a pamphlet published in 1853 [1] advocated the progressive development of organic forms on the earth. "Thus living plants and animals are not separated from the extinct by new creations, but are to be regarded as their descendants through continued reproduction." He accounts for the distinction of species by the destruction of graduated intermediate forms.

The Rev. Baden Powell, in his "Essay on the Unity of Worlds," published in 1853, maintained that the introduction of new species is "a regular, not a casual phenomenon," that is, "a natural in contradistinction to a miraculous process," as stated by Sir John Herschel.

In 1858 Mr. Charles Darwin and Mr. Wallace published their views on the origin of species, and gave a great impetus to the subject.[2]

Professor T. H. Huxley, in a lecture "On the Persistent Types of Animal Life" delivered at the Royal Institution, London, in June 1859, says: "It is difficult to comprehend the meaning of such facts as these, if we suppose that each species of animal and plant, or each great type of organisation, was formed and placed upon the surface of the globe at long intervals by a distinct act of creative power; and it is well to recollect that such an assumption is as unsupported by tradition or revelation as it is opposed to the general analogy of nature. If, on the other hand, we view 'Persistent Types' in relation to that hypothesis which supposes the species living at any time to be the result of the gradual modifications of pre-existing species—a hypothesis which, though unproven, and sadly damaged by some of its supporters, is yet the only one to which physiology lends any countenance—their existence would seem to show that the amount of modification which living beings have undergone during geological time is but very small in relation to the whole series of changes which they have suffered."

The opinions of numerous other authorities whose names carry weight might be cited in this connection, but enough has been said to show that great divergence of view exists as to fundamental matters of the first importance. The preponderance of the evidence quoted is in favour of finality and a First Cause. Without a Creator or First Cause, difficulties spring up on all hands. It is difficult, for example, to understand how, if species are manufactured from varieties, the stage of finality is reached, where stability of form and infertility occur. Without a First Cause there can be no beginning, no continuity, and no end. If changes and improvements, in the case of species, are possible up to a certain point, why do they not continue? If existing species are descended from other and older species, whence came the originals? If all species are descended from a single parent form, a variety is as important, in a way, as a species. If endless modification in endless time is required to make a species, and if there are sub-species and varieties and gradation, there is no halting-place between the point of departure and the point reached: the traces of a plan become indistinct, and classification impossible. In other words, the divisions into classes, orders, sections, families, sub-families, genera and species disappear, and all that is left is an interminable catalogue of varieties from the monad to the man.

The production of species by modification and advance precludes, in great measure, the existence at the present day of the simpler vegetable and animal forms; sufficient time having elapsed since the creation of the world for their conversion into something more complex and higher. The manufacture of species by modification and natural selection from varieties and lower forms necessitates starting-points, and living centres traceable either to creative acts or spontaneous generation; spontaneous generation being a discredited and impossible doctrine. A species cannot be produced from nothing. It must have a beginning. Mere variation in a plant or an animal does not materially affect the question of type; neither does it interfere to any marked extent with the main

[1] "Verhand. des Naturhist. Vereins der preuss. Rheinlands," &c.
[2] *Journal of the Linnæan Society*, vol. iii.

divisions into which the plants and animals constituting the organic kingdom may be divided. The great races of plants and animals have their limits, their boundaries, which they may not overrun. The oldest fossil plants and animals have their representatives on the earth at the present day. This, however, is not due to the origin of species by means of natural selection, or evolution, but to the persistence of created living types. The monuments and tombs of Egypt display figures of plants and animals which have not changed in the least for ten thousand or more years.

While a certain amount of variation in plants and animals undoubtedly takes place, the persistence of types through countless ages cannot be denied. While there can be no reliable history of varieties, the history of types is literally engraved on the rocks, and is in evidence and bears testimony at the present day.

The absence of connecting links is more or less fatal to the theory of the origin of species by variation, natural selection, and descent. The reversion of cultivated plants and animals to simpler, and, in a sense, lower forms is also inimical to it. If a plant or animal which has been improved by human *artificial* selection reverts or breeds back, the *raison d'être* of the origin of species by *natural* selection or progressive variation is virtually swept away: the law of progress is turned aside by retrogression and the innate tendency to breed back. The changes in the inorganic kingdom are not more constant than those in the organic kingdom, and the changes in the one and the other are, in every instance, consentaneous and correlated. From the beginning it was so. At the outset, no plant or animal could exist on the earth: a soil, an atmosphere, moisture, a suitable temperature, winds, &c., had to be provided. Rudimentary plants appeared on the scene and were followed by rudimentary animals. As the external conditions of life improved, the plants and animals became more complex in an ascending series; the complex plants and animals not necessarily being the product or direct descendants of the more simple. In other words, the more complex plants and animals appeared as the more simple had done, namely, when the proper time arrived, and when cosmic changes had made the world a fitting habitation. In no case did the higher plants and animals appear out of season, and in no case were they not adapted to their surroundings, or deprived of the power of accommodating themselves thereto.

The inorganic and organic kingdoms have always advanced *pari passu*. Change in the one in every instance meant change in the other. Nature were otherwise out of joint in her finer adjustments. The means and ends of existence, the finality, the fixity, the law and order, the traces of design everywhere apparent, demanded this state of things.

If the operation of a First Cause be admitted, it matters little whether that cause acts once and for all, at intervals, or continuously. The creative and directive agency is responsible for everything that exists. It cannot be doubted that law and order prevail equally in the physical universe and in the universe of plants and animals. The prevalence of law eliminates the element of chance. It also excludes the possibility of spontaneous generation.

Only two explanations can be given. We must accept, either (*a*) a Creator and law and order for everything that exists, animate and inanimate, or (*b*) spontaneous generation and chance, and matter and force as the products thereof.

According to the former (*a*), limits and boundaries are a necessity, and are imposed upon everything, living and dead. According to the latter (*b*), the limits are blurred, doubtful, or non-existent.

The belief in a First Cause is essentially based on law, order, and types. It is more natural to suppose that varieties are departures from standards, than that standards are derived or built up from varieties. This argument is strengthened by infertility and so-called finality of what are considered true species, and by the reversion of cultivated plants and animals to their originals, if left to themselves and allowed to run wild.

As regards the belief that plants and animals improve in time, it is to be noted that the plants and animals of a bygone era were as well adapted to their surroundings as present plants and animals are adapted to theirs. If, to take an extreme example, modern educated man is a great advance on ancient (not necessarily) savage man, the advance is very largely in one direction, and is nervous and intellectual in character. The plant and animal are physically fit from the beginning. In making this statement I am not unmindful of the long, toilsome, upward plodding of so-called primitive man through the stone, flint, and bronze ages to his present exalted position in the iron or what some will be inclined to regard the golden age. In this connection, it is proper to state that the majority of theologians, and a considerable number of scientists, do not subscribe to the lowly origin theory of man, but regard him as a being apart—a separate creation—possessing intellectual and moral qualities which as regards quantity and quality place him in a distinct category by himself.[1] This is the view advocated in Holy Writ. At the present time no nervous system or intellect, in the ordinary sense, can be attributed to plants.

While plants and animals have in all ages been physically fit, and perfectly adapted to their surroundings, it

[1] Mr. Wallace has sought to prove the separate and independent creation of man by contending that his intellect is out of all proportion to his requirements, even as the acknowledged head of the animal kingdom.

curiously enough happens, that the general forward movement or advance has occasionally been characterised by retrogressions, and even the disappearance of prominent forms. There are distinct traces of a swing back of the pendulum in the histories of both plants and animals ; nor is man in any way an exception. Civilisation, as we know it, favours the idea of progress and retrogression. All the great nations of the earth, hitherto, have advanced up to a point, and then, slowly but surely, declined. In the vegetable and animal kingdoms cases of advance, retrogression, and extinction are by no means infrequent. The retrogressions are illustrated by vegetable and animal parasites as a class. In both plants and animals high-water marks have been reached in time and space which can no longer be attained. The tree ferns afford examples among plants, and the cuttle-fishes among animals. The splendid tree-ferns of geological times outrival in size and grace anything at present existing on the earth, and the cuttle-fishes (especially the Nautiloidæ) of the remote past transcend in complexity and ornament their modern congeners, beautiful though they be.

The Nautiloidæ greatly abounded in the Ordovician, Silurian, Devonian, Carboniferous, Permian, and Trias ages. They became suddenly reduced in the Jurassic, Cretaceous, and Tertiary periods, and at the present time the nautilus is their sole representative. The life history of the Nautiloidæ is interesting and instructive. According to Karl A. Von Zittel, who may be quoted as an authority, "An abundant Cephalopodan fauna makes its appearance in the earliest Calciferous, and is quite distinct from other later assemblages. . . . All the sub-orders of *Nautiloidæ* are initiated in the Ordovician, and one of them (*Schistochoanites*) is confined to this period. *Holochoanites* and *Mixochoanites* become extinct in the Silurian, and only *Orthochoanites* survives the Palæozoic. The sub-orders that disappear at this early date are remarkable for their complicated siphuncular structure, and peculiar sigmoidal septa observed in the gerontic living chambers of certain forms (*Ascoceras*, *Gonioceras*), while their prevailing habit is gyroceraconic. . . . The gyroceracones disappear with the Carboniferous, and the more discoidal nautilicones with the Trias. . . . The first manifestation of torticones is in the Ordovician, and their acme is attained during the Silurian. As regards ornamentation, annulated shells appear in the Calciferous, and those with longitudinal ridges later in the Ordovician, together with tuberculated and costated gyroceracones and nautilicones. The last-named, however, are much more abundant in the Devonian and Carboniferous, after which they disappear. Very highly ornamented shells exist in the Trias, but following this period the conches are smooth.

"Very striking is the marvellously sudden rise of the *Nautiloidæ* as a group, reaching its maximum in the Silurian, and followed by a decline extending from the Devonian to the Trias. Then the forces acting unfavourably upon their existence were arrested, or their violence lessened, and the group has been affected by only very slight changes and an exceedingly slow process of retrogression until the present time. The acme of siphuncular differentiation occurred in the Ordovician, of general morphic diversity in the Silurian, of ornamentation in the Devonian, and of sutures in the Trias. . . .

"During the Cretaceous and Tertiary the principal distribution of the *Nautiloidæ* was in the eastern hemisphere, and the last surviving species of *Nautilus* are now restricted to Oriental waters." [1]

Similar remarks are to be made of the Gastropoda, with this notable difference, that these have been increasing while the Nautiloidæ have been decreasing.

Having regard to the fact that the inorganic kingdom was formed before the organic ; that plants and animals were conditioned and appeared on the earth in a certain order and succession, the simplest first, and the most complex last (the plants depending on inorganic matter for their food, and the animals on plants or other animals) ; considering, further, the persistency of types in plants and animals, and the fact that man has not materially altered in construction for the last ten thousand years, it is more reasonable to believe that the world and all it contains is the outcome of a definite plan in which law and order are supreme, where limits are set to all things living and dead, and where types are a necessity, than that it is the result of chance, and the product of endless modifications in unlimited time where utilitarian considerations alone prevail.

The inorganic and organic kingdoms are parts of a great whole ; the latter being indebted to the former for its materials and much of its force, both in the way of original building up and of food. The inorganic and organic kingdoms are in reality complemental. Both are under control, and subject to virtually the same laws.

As climatic and physical changes are necessary to the well-being of plants and animals, it follows that the Great Architect and Arch Designer had to subordinate everything to given ends ; had to provide and regulate day and night ; the seasons ; the state of the atmosphere ; the variations of moisture and drought ; the thermic conditions, &c.

All these arrangements point to design, supervision, and fixity of a kind in everything organic and inorganic. Of this we have proof in the physical universe, and in the general plan and construction of living things.

The heavenly bodies are built up in accordance with physical laws, and their movements are determined by gravitation and other forces which are constantly at work on a grand scale. The birth and death, and the out-

[1] "Text-book of Paleontology," by Karl A. Von Zittel, translated by Charles R. Eastman, Ph.D. 1900, vol. i., pp. 533–4 *et seq.*

goings and incomings, and all the movements and changes occurring in plants and animals, are likewise predetermined and controlled. The smooth working of the cosmos demands law and order in the construction and movements of everything in the organic and inorganic kingdoms. A careful examination of the mode of formation of crystals and of the construction of plants and animals conclusively shows that the organic and inorganic kingdoms have much in common.

Crystallisation as a rule proceeds from a central point; the additions of matter being from *without*. Similarly, plants and animals spring from a central cell or its representative, and growth takes place from *within*. The increase of substance in the crystal and in the plant and animal follows two principal directions; the matter being arranged for the most part in radiating and concentric lines, to which, in some cases, a certain degree of spirality and branching is added. The radiating and concentric arrangements are seen in numerous crystals, and in the growth of the stems, flowers, and fruit of plants; in shells, the scales of fishes, and in the bones, horns, teeth, hairs, and other parts of animals.

Not only is there a general resemblance in many cases as between crystals, plants, and animals as such (Plates xxiii., xxiv., xxv., and xxvi., pp. 40, 41, 42, and 43), but colonies of animals arrange themselves on the same plan, and assume forms identical with those of individual plants and animals or parts thereof. Thus colonies or aggregates of zooids assume, in many cases, the plant form so perfectly that they are not unfrequently mistaken for plants (Plates xxxv., xxxvi., and xxxvii., pp. 55, 57, and 58). The contour of the brain coral is an exact reproduction of the convolutions of the human brain (Plate xliv., Fig. 2, p. 71), and the structure of Venus's flower-basket resembles that of the left ventricle of the heart (Plate xliv., Fig. 8).

These resemblances are not accidental. They point to a law of development in organic and inorganic forms as apart from consanguinity and descent. They are opposed to the belief that everything grows out of every other thing: they indicate independent lines of descent. They bespeak development and differentiation, not in one, but in many directions.

In crystals and in plants and animals there is a repetition of parts, and in many cases a well-marked tendency to longitudinal or transverse cleavage, or both (Plates ii. and iii., pp. 5 and 6; Plates xl. and xli., pp. 63 and 66). This appears in dendritic formations, where crystals arrange themselves as in the branches of trees (Plates ii., xxxiv., xxxv., and xxxvi., pp. 5, 54, 55, and 57). The repetition of parts and branching are also seen in plants and animals of all kinds and all parts thereof (Plates iii., xxv., xxvi., xxviii., xxxv., xxxviii., and xxxix.). It is especially obvious in the Infusoria and other rudimentary animals where the first traces of structure appear (Plates lxvi. to lxxv. inclusive, pp. 165 to 178). In these, longitudinal and transverse and also spiral markings and branching can readily be made out. In the radiating, concentric, and spiral arrangements, and in the longitudinal, transverse, and spiral markings and cleavages referred to, are to be traced nearly all the peculiarities of structure, growth, and movement met with in the organic and inorganic kingdoms.

A general plan it appears to me underlies *everything*, and there is no need to assume, as is constantly done, that all living things are manufactured out of each other in a graduated manner, in endless sequence, from the simple zooid up to the monkey or the man. There is no actual proof that such is the case in embryology, morphology, anatomy, biology, or physiology. There are relationship and consanguinity within the several types and orders of plants and animals, whereby each produces its like and establishes pedigree and heredity, but this is quite another thing from saying that the monad is the parent of the man at the millionth remove.

If radiating, concentric, and spiral structures and movements obtain in plants and animals from the lowest to the highest, and if plants and animals are divided longitudinally and transversely where differentiation occurs, there is no need and indeed no excuse for saying that a vertebrate animal with a backbone is merely a higher form of an articulate animal, or that the higher vertebrates are the lineal descendants of the lower vertebrates. There is no absolute need for connecting links, and an unbroken chain of descent and consanguinity. The different orders of plants and animals constructed on a general, and, within limits, a progressive plan, can well afford to be regarded separately as so many independent units, notwithstanding all that is known regarding development and modification in time and space.

The multiplicity of plants and animals, and their variations, can all be accounted for by referring them to a general plan with types, which adapts them to their surroundings, apart from transitions and connecting links. Indeed the absence, in a large number of cases, of these links in time and space stultifies the belief in their existence.

The idea of a general plan is favoured by Von Baer in the following words: "The embryos of mammalia, of birds, lizards, and snakes, probably also of chelonia, are in their earliest states exceedingly like one another, both as a whole and in the mode of development of their parts; so much so, in fact, that we can often distinguish the embryos only by their size. In my possession are two little embryos in spirit, whose names I have omitted to attach,

and at present I am quite unable to say to what class they belong. They may be lizards or small birds, or very young mammalia, so complete is the similarity in the mode of formation of the head and trunk in these animals. The extremities, however, are still absent in these embryos. But even if they had existed in the earliest stage of their development we should learn nothing, for the feet of lizards and mammals, the wings and feet of birds, no less than the hands and feet of man, all arise from the same fundamental form."

Haeckel, who holds extreme evolutionist views, has published a series of drawings, which I reproduce (Plate xciii., Fig. 9, p. 403), showing how vertebrate types in their embryonic stages resemble each other. These drawings, it appears to me, indicate a general plan, rather than consanguinity and descent from a common parent.

The metamorphoses of insects, and the "alternate generations" of certain lower animal forms, strengthen the argument of a general plan by furnishing examples of cycles of changes very striking and different in character which begin and end in a precisely analogous manner. Mr. Darwin observes that "the metamorphoses of insects are generally effected abruptly by a few stages: but the transformations are in reality numerous and gradual, though concealed. A certain ephemerous insect (*Chlöeon*) during its development moults, as shown by Sir J. Lubbock (now Lord Avebury), above twenty times, and each time undergoes a certain amount of change; and in this case we see the act of metamorphosis performed in a primary and gradual manner. Many insects, and especially certain crustaceans, show us what wonderful changes of structure can be affected during development. Such changes, however, reach their climax in the so-called alternate generations of some of the lower animals. It is, for instance, an astonishing fact that a delicate branching coralline, studded with polypi and attached to a submarine rock, should produce, first by budding and then by transverse division, a host of huge floating jelly-fishes; and that these should produce eggs, from which are hatched swimming animalcules, which attach themselves to rocks and become developed into branching corallines; and so on in an endless cycle. The belief in the essential identity of the process of alternate generation and of ordinary metamorphosis has been greatly strengthened by Wagner's discovery of the larva or maggot of a fly, namely the Cecidomyia, producing asexually other and similar larvæ. . . . The vermiform larvæ of moths, flies, beetles, &c., generally resemble each other much more closely than do the mature insects: but in these cases the embryos are active, and from having been adapted for special lines of life, sometimes differ much from each other."

It is to be remarked in connection with "alternate generations" that if any one animal can assume such a variety of forms during its life history, there is no room for wonder if animals, essentially different, should have apparently a common origin, and, during their development, pass through stages seemingly common to all.

There is no need to suppose that because a mammal *in utero* assumes certain characters seen in the fish, the reptile, or the bird, that it is evolved from any of these. The mere developmental metamorphoses do not establish consanguinity, identity, or descent. A mammal cannot be produced from the egg of a fish, a reptile, or a bird, and similarity of embryonic arrangements bespeaks a general plan rather than descent from a common stock. It amounts to a moral certainty that the great divisions of animals are distinct and separate from the beginning, even from the eggs, and that embryonic resemblances are mere trifles in view of this great fact. Moreover, the changes which separate the mammal from the bird, the bird from the reptile, and the reptile from the fish, are continuous. They begin in the fecundated eggs and go on steadily through the embryonic period. What are apparent resemblances result in well-marked differences. It is the mature rather than the immature animals which are to be compared and classified. In the embryos there are apparent similarities: in the fully developed animals there are real differences.

The true test of value as regards similarity or dissimilarity is function as revealed by adaptation to the various modes of life. This is the ultimate goal of all differentiation, and to it are to be attributed the marvellous modifications which result in the fins and tail of the fish, the flippers and tail of the whale, the wings and feet of the bird, and the hands and feet of the man. These one and all afford examples of design: they are means to ends, and they are necessities when the several modes of life are considered. Mere modification as apart from function has little significance.

It does not follow that because plants and animals approach each other indefinitely near in structure and function, even in an ascending consecutive series, that the units of the series are remotely or immediately related. The bricks cast in the same moulds do not testify to the character of the edifices into which they ultimately enter. The plan of the architect alone separates the hovel from the palace, and the hamlet from the city. So with the lower and higher plants and animals throughout the vegetable and animal series. It is a question not of materials, but of plan. The materials or elements out of which plants and animals are constructed are, roughly speaking and to a large extent, the same, and all are formed upon essentially the same lines. The units are arranged according to law, order, and design, and no plant or animal is necessarily beholden either for its existence or its maintenance to its neighbour, however close the proximity of that neighbour.

The successful crossing of plants and animals having affinities, and the infertility of others lacking affinities, go

far to prove the independence of plants and animals, and the existence of a general plan with types and limits as distinguishing features.

In estimating the life histories of plants and animals it is necessary to direct attention to the influences and stimulation said to be exerted by environment. The prevailing belief that plants and animals are irritable, and that their activities are evoked by extraneous stimuli, is, I believe, founded in error. Plants and animals, so far as I can make out from observation and experiment, act, as a rule, spontaneously and independently; and stimulation takes effect rather in abnormal pathological than in normal physiological conditions. Plants and animals are not automata, but living, sentient entities, which inaugurate and regulate, within limits, all the changes which occur in them. They are expressly co-adapted to their surroundings, and are very little affected by environment.

A plant or an animal may be exposed to an excess of heat or cold, of dryness or moisture, and have a superabundance or scanty supply of food, and may, as a consequence, be overgrown or stunted, but the structure and constitution of the plant or animal are not thereby materially or permanently altered.

Environment does not produce structural changes of any magnitude, and it never produces organs: these are the outcome of design, and of vital changes in the plants and animals themselves.

Mr. Wallace, in his "Darwinism," quotes a declaration of Mr. Darwin's to the effect, that it is almost impossible to conceive how the first rudiments of important organs can have been of any use; or how, if they were not of any use, they can have been preserved for further development by natural selection. If Mr. Darwin conceded so much, the position ultimately taken up by him is, to a great extent, unintelligible. The gist of the argument in favour of "the origin of species by natural selection" lies in the assumed power to produce and perpetuate *useful improvements;* but if the rudiments of important organs were of no use to begin with, they could not, according to the theory, have been selected and perpetuated.

Mr. Darwin may be said to have altogether failed to account for the origin and development of important organs. He experienced very special difficulties in his attempt to account for the compound eye—so much so, that Mr. Wallace reports him to have said that to the last he felt a cold shudder when he thought of it. He was also considerably perplexed when confronted with the problem of the origin and development of the electric organs of certain fishes.

A recent writer (1903), discussing the evolution of the eye, remarks: "One feature which distinguishes the eye from all the other structures in the body is that it is formed in accordance with regular geometrical figures. If we suppose that intelligence was concerned in designing it, we should at once understand that this is due to the reason which induces manufacturers of telescopes, microscopes, and eye-glasses to make their instruments in geometrical forms—that is, they are acquainted with the laws of optics. But, as chance knows nothing of optical laws, it is not easy to understand why forms produced accidentally and without any intervention of intelligence should conform to these laws. If there was no conformity, why should the nascent organ, which has resulted in the beautifully designed and skilfully executed instrument which we use, conform to them as carefully as if it had been designed by a mathematical professor, and executed by a skilful workman?"

The same writer offers the following observations on the development of the electric organs: "How long a time must the installation have taken if the ordinary flesh and nerves of the fish had to be converted into the materials of the battery, and the battery itself be constructed—if all this was to be done by the Darwinian method of small variations, occasional occurrence of a beneficial variation, and no exercise of intelligence by any one to be allowed to guide and accelerate the process? One is afraid to estimate through how many generations of fishes the accumulations of small variations must have gone on before the machine was completed, even if we admit that by the Darwinian method the work would ever come to an end. And during all this time the unfortunate fish must have been dragging about this heavy encumbrance (we are told that one-third of the body of the gymnotus is occupied by his electric battery), which did him no good, and impeded him alike when he tried to escape from the marine animal who wished to eat him and when he tried to catch the little fishes whom he wished to eat."

Mr. Darwin, in his "Origin of Species," makes no distinction between the evolution of new organs, and modifications and improvements in general, from which it follows that he regards "natural selection" as the efficient cause of all.

While Mr. Darwin's theory does not satisfactorily account for the production of structures and organs, still less does it account for the power of reproduction, the parental instincts, and the origin of consciousness. His explanation, moreover, of instinct itself is subversive of the principle of natural selection which makes for improvement and advance. He asserts that those actions which are now performed automatically by animals were originally performed by intelligence, and the explanation he gives is that in the remote past some animals were sufficiently intelligent *to discover advantages and turn them to account*, and that by the repetition of certain actions a habit was formed, which habit was transmitted to the offspring and enabled it to act intuitively or without thought. Instinct in the offspring, it will be observed, takes the place of intelligence in the remote ancestors; a lower attribute usurps

the place of a higher; which means that there is a retrogression instead of the advance which natural selection is supposed to produce (the subject of instinct in relation to intelligence is discussed further on). If, moreover, Mr. Darwin's argument applied to animals, it could not apply to plants, which have no nervous systems and do not form habits.

§ 213. Consideration of the Theory of the Origin of Species by means of Natural Selection—Objections to the Theory.

Mr. Darwin is to be regarded as the great modern exponent of the origin of species by means of natural selection. While he has treated the subject at great length and with exemplary patience and zeal he is by no means decided or confident as to his conclusions. It would have been fortunate for science if his followers and disciples had treated the subject in the same cautious, tentative way, and with the same modesty and reserve. Practically, they have rushed in where Mr. Darwin feared to tread, and have boldly and inconsistently stated as fact what he, in many cases, considered unproved and extremely doubtful.

Mr. Darwin's indecision on many points will appear from the following quotations from the fifth edition of his celebrated work, "On the Origin of Species by means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life."[1]

He writes: "In considering the origin of species, it is quite conceivable that a naturalist, reflecting on the mutual affinities of organic beings, on their embryological relations, their geographical distribution, geological succession, and other such facts, might come to the conclusion that species had not been independently created, but had descended, like varieties, from other species. Nevertheless, such a conclusion, even if well founded, would be unsatisfactory, until it could be shown how the innumerable species inhabiting the world have been modified, so as to acquire that perfection of structure and co-adaptation which justly excites our admiration. Naturalists continually refer to external conditions, such as climate, food, &c., as the only possible cause of variation. In one limited sense, as we shall hereafter see, this may be true; but it is preposterous to attribute to mere external conditions the structure, for instance, of the woodpecker, with its feet, tail, beak, and tongue, so admirably adapted to catch insects under the bark of trees. In the case of the mistletoe, which draws its nourishment from certain trees, which has seeds that must be transported by certain birds, and which has flowers with separate sexes absolutely requiring the agency of certain insects to bring pollen from one flower to the other, it is equally preposterous to account for the structure of this parasite, with its relations to several distinct organic beings, by the effects of external conditions, or of habit, or of the volition of the plant itself."

Mr. Darwin, it will be observed, in the passage quoted attaches comparatively little importance to environment or external conditions (climate, food, &c.) in the production of the several parts of the woodpecker and the mistletoe. These he obviously refers to original endowment, to something inhering in the animal and plant respectively. The woodpecker and mistletoe are obviously designed organisms carefully adapted to their surroundings, and, as such, the work of a Creator. It is necessary to direct the attention of the reader to these points, because Mr. Darwin, in other passages, largely relies on external conditions (climate, food, &c.) for the modifications and variations which constitute his species. Thus he states: "Changed conditions of life are of the highest importance in causing variability, both by acting directly on the organisation, and indirectly by affecting the reproductive system. . . . Variations of all kinds and degrees are directly or indirectly caused by the conditions of life to which each being, and more especially its ancestors, have been exposed."

He assigns to the woodpecker and mistletoe "that perfection of structure and co-adaptation which justly excites our admiration," and infers that the innumerable species inhabiting the world have been modified and altered until perfection has been secured. He assumes that perfection in plants and animals can only be attained by altering, modifying, and remodelling—a somewhat impotent conclusion considering the extraordinary perfection of nature as a whole. Admitting, however, that the altering, modifying, and remodelling actually occur, they can only take place in one of two ways: either through the agency of a Creator Who made the plant and animal, and Who maintains and supervises both; or the plant and animal must possess in themselves, as apart from a Creator, the power to alter and modify themselves *ad libitum*; a power the possession of which, for reasons to be stated presently, I am prepared to dispute. The subject narrows itself to this: the alterations and modifications in question must be referred either to a First Cause (the Creator) and design, or to secondary causes and chance, apart from a First Cause. Mr. Darwin chooses the latter alternative, and substitutes for a First Cause and design what, for practical purposes, must be regarded as secondary causes and chance. In so doing he vitiates his own argument, for the

[1] Published by John Murray. London, 1869.

attainment of perfection by plant and animal in virtue of alterations and modifications implies design, and a power working steadily in a particular direction to attain it, the power being outside or inside the plant and animal, or partly the one and partly the other, but under supervision.

In the complex case of the mistletoe, design and supervision become a necessity: mere chance would never account for the complex relations of the parasite to the trees it infests, nor for the visits of birds to distribute its seeds, and of insects to carry its pollen from flower to flower. Mr. Darwin experiences a difficulty in explaining the existence of the mistletoe, for he says it would be "preposterous to account for the structure of this parasite . . . by the effects of external conditions, or of habit, or of the volition of the plant itself." It will be noted that Mr. Darwin credits the plant with volition and the power of forming habits apart from a nervous system. In the sentences quoted, he excludes external conditions (climate, food, &c.); he also takes for granted but excludes habit and volition in the plant itself. If, however, externalities and the internalities (implied in habit and volition) do not make the plant what it is, we can only fall back on a Creator or First Cause.

Mr. Darwin proceeds with his argument as follows: "It is, therefore, of the highest importance to gain a clear insight into the means of modification and co-adaptation. At the commencement of my observations it seemed to me probable that a careful study of domesticated animals and of cultivated plants would offer the best chance of making out this obscure problem. Nor have I been disappointed; in this and in all other perplexing cases I have invariably found that our knowledge, imperfect though it be, of variation under domestication, afforded the best and safest clue. I may venture to express my conviction of the high value of such studies, although they have been very commonly neglected by naturalists. . . . As many more individuals of each species are born than can possibly survive, and as, consequently, there is a frequently recurring struggle for existence, it follows that any being, if it vary however slightly in any manner profitable to itself, under the complex and sometimes varying conditions of life, will have a better chance of surviving, and thus be *naturally selected*. From the strong principle of inheritance, any selected variety will tend to propagate its new and modified form."[1]

In the last clauses of the passage quoted, Mr. Darwin *assumes* or postulates, without proof, the existence of "natural selection" and the "transmission and perpetuation of variations." Natural selection, if it means anything, can only mean Nature or God selection. No plant or animal can select and perpetuate its profitable or useful properties and qualities to the suppression or exclusion of its unprofitable or non-useful properties and qualities, provided such there be, apart from the Creator, Designer, and Upholder of the Universe. In other words, plants and animals cannot divest themselves of their original endowments, and alter their constitutions. They have no power to originate, and, still less, to perpetuate, variations, unless under special direction and according to a general plan. That plants and animals do vary slightly at times is quite true; but it is also true that the plants and animals which vary, if left to themselves, invariably breed back and revert to their originals. The perpetuation of the variations can only be secured by the intervention of an intelligent agent. Natural selection, as a matter of fact, implies a selector; and the argument hinges, very largely, on the meanings attached to the terms "natural selection" and "artificial selection." These terms, which in one sense are the opposite of each other, are, in the strictest sense, correlated, and what is predicated of the one can certainly be predicated of the other. In both natural and artificial selection a selector is a necessity. In artificial selection as applied to plants and animals, the selectors are the intelligent advanced horticulturists and the scientific breeders of stock. Nothing can be claimed for natural selection which cannot be equally claimed for artificial selection. A selector is as necessary in the one case as in the other, if variations are to be transmitted and rendered permanent. Not only so, the selector in either case must be constantly on guard and at work. Nothing must be left to chance. It is a misuse of language to say that natural selection fundamentally differs from artificial selection in so far as the necessity for a selector is concerned. The inexact use of language in this and similar cases gives rise to confusion and serious misunderstandings, and provides, it appears to me, the stumbling-block on which "natural selection," as a theory, has tripped.

As regards Mr. Darwin's statement that "many more individuals of each species are born than can possibly survive, and that consequently there is a frequently recurring struggle for existence," I have to observe that Nature never intended that the teeming millions of plants and animals should survive. On the contrary, they are, for the most part, specially set apart for destruction: they form, and inevitably form, food for each other. Death is a recognised factor in the scheme of life. There is consequently no need for the so-called *profitable variations* to which Mr. Darwin attaches so much importance, and, assuredly, the variations in question (provided they occur) cannot be "naturally selected" in the sense Mr. Darwin indicates—plants and animals, as explained, having no power, apart from a First Cause, to select and perpetuate what is best in themselves to the exclusion of their less desirable properties. The survival of the fittest is not due to accidental *profitable variations*, but to design and a general plan

[1] Op. cit., pp. 3, 4, and 5.

which weeds out the less desirable individuals both in plants and animals. The persistency of plants and animals in time and space for thousands of years negatives the argument for variation, and, especially, for the indefinite and practically infinite variation and the transmission of variation for which Mr. Darwin contends.

It will be observed that Mr. Darwin invites a comparison and draws a parallel between "natural selection" and "artificial selection" as practised by man on plants and animals. In the latter case the elements of intelligence, volition, and intention or design figure prominently, and it becomes a question whether, strictly speaking, the phrase "natural selection" can, under the circumstances, be applied to plants and the lower animal forms, where intelligence, volition, and intention or design are denied or excluded. Personally, I do not think it can. The phrase "natural selection," in my opinion, implies intelligence, volition, and design, or their equivalents, exercised either by a First Cause or by the individual plants or animals themselves acting under guidance. Of course it is quite conceivable, and indeed more than probable, that plants and the lowest animal forms (being conditioned and guided and under the influence of a First Cause) take the initiative in every change, progressive or retrogressive, which occurs in them at every period of their life histories, but this does not amount to "natural selection" in the sense in which the term is employed by Mr. Darwin, where a First Cause and Design are denied. The phrase "natural selection" of necessity takes for granted and involves the power to select, but the power of selecting is, in nature, outside the plant and animal, precisely in the same way that it is outside the plant and animal in "artificial selection." It is exerted by the Creator or First Cause alone, and represents the innate capacity conferred on plants and animals to modify and adapt themselves, within limits, to altered circumstances during their lives. Plants and animals have no power to vary their structure and perpetuate the variation *as apart from design and the operation of a First Cause.* The variations and adaptations are to be traced to the intelligence which pervades and regulates the universe.

What is true of artificial selection is almost certainly false of natural selection in the Darwinian sense. No plant or animal (man included) can of itself, and independently, add to or take from its structural and fundamental endowments. We have proof of this in our own persons. We cannot (however much we may wish or will it) control the growth of any part of our bodies; we cannot control our circulation, our respiration, our digestion. We cannot voluntarily add to or take from our stature. If a peculiarity appears in any part of our bodies it is not necessarily transmitted: the chances are it will disappear during the next generation. If, again, any part of the body be removed on account of disease or accident, the progeny (provided there be any) bears no trace of the mutilation. So little can parents control the structural and functional attributes of their offspring, that children are continually being born with serious physical and mental defects. If, however, man with his boasted wealth of imagination, thought, and power of will, is helpless to alter himself even in the slightest detail, how much less will the lower animals and plants have power to produce the stupendous changes which the origin of species by means of natural selection requires. If man, the lower animals, and plants cannot modify themselves, it follows that they cannot select and perpetuate their best parts and properties to the exclusion of the more doubtful. The inability to select and perpetuate what is best renders the theory of the origin of species by means of natural selection untenable. The theory rests on the tendency to vary, and the power to perpetuate endless modifications of a profitable and progressive character in, practically, unlimited time; but if the power to modify does not exist, an eternity of time will not bring about the desired results.

Mr. Darwin in further developing his argument states that the doctrine "that each species has been independently created is erroneous," and adds, "I am fully convinced that species are not immutable: but that those belonging to what are called the same genera are lineal descendants of some other and generally extinct species, in the same manner as the acknowledged varieties of any one species are the descendants of that species. Furthermore, I am convinced that natural selection has been the most important but not the exclusive means of modification."[1]

In these passages it will be noted that Mr. Darwin objects to the separate creations of species, and expresses his conviction that existing species are the descendants of extinct species, and that species are mutable in the sense that varieties are. There is, according to him, no fixity: there are points of departure for the species and for the variety, but there is no goal for either. It is a case of premises without a conclusion—a road without an end.

If, however, species cannot be traced to creative acts, and are continually changing, they, in a great measure, cease to be objects about which the human mind can reason. A definition of species under the circumstances becomes impossible. Mr. Darwin was fully aware of this dilemma and frankly admitted the difficulty.

§ 214. The Origin of Species Undetermined and Indeterminable.

Mr. Darwin thus expresses himself as regards species and varieties: "No one definition has as yet satisfied all naturalists; yet every naturalist knows vaguely what he means when he speaks of a species. Generally the term

[1] Op. cit., p. 6.

includes the unknown element of a distinct act of creation. The term 'variety' is almost equally difficult to define; but here community of descent is almost universally implied, though it can rarely be proved. We have also what are called monstrosities; but they graduate into varieties. By a monstrosity I presume is meant some considerable deviation of structure, generally injurious to or not useful to the species. Some authors use the term 'variation' in a technical sense, as implying a modification directly due to the physical conditions of life; and 'variations' in this sense are supposed not to be inherited: but who can say that the dwarfed condition of shells in the brackish waters of the Baltic, or dwarfed plants on Alpine summits, or the thicker fur of an animal from far northwards, would not in some cases be inherited for at least some few generations? In this case I presume that the form would be called a variety. It may be doubted whether sudden and great deviations of structure such as we occasionally see in our domestic productions, more especially with plants, are ever permanently propagated in a state of nature. Almost every part of every organic being is so beautifully related to its complex conditions of life that it seems as improbable that any part should have been suddenly produced perfect, as that a complex machine should have been invented by man in a perfect state."[1]

It will be seen from the passages just quoted that the foundations on which the imposing edifice of the origin of species by means of natural selection rests are by no means stable or well defined.

If the naturalist only knows *vaguely* what is meant by a species, if a species cannot be satisfactorily defined, and if varieties are differently regarded by different authorities, it is evident that no true finding can be arrived at, and the whole subject is more or less in the air. No amount of speculation or special pleading can relegate the doctrine of "the origin of species by means of natural selection" to a place in the exact sciences. The suggestion that plants and animals are indefinitely modified before they arrive at perfection, as a machine is perfected by the addition of successive parts by man, is illusory, in so far that it seeks to establish an analogy and a comparison between the products of the Infinite Mind, with a knowledge of all possible requirements, and the finite mind, which has to grope its way to attain even imperfect results.

Professor John Goodsir makes the following pregnant observations regarding species. He says: "A species can only exist over a geographical area having certain conditions of geological structure, of climate, and of animal and vegetable forms. The characters of the living economy of an animal species may, indeed, become more or less modified, or the number of its individuals may diminish, in accordance with modifications in the cosmical conditions of its area of distribution. But there is a limit to such permitted modifications of specific character; and if the cosmical conditions of its existence pass these limits, the species disappears. . . . Each species of animal was directly created for its proper area. . . . The conscious element of an animal is virtually the animal itself; for it is that, failing which the body of the animal would have had no existence. It is that element in the animal constitution which is immutable.

"For although the constituent parts of the corporeal structure of the horse, dog, or pigeon, along with the instincts co-ordinate with those parts, may, by certain natural or artificial rearrangements of the specific conditions of the animal's existence, undergo very great modifications, nevertheless, the fundamental attributes of its conscious element—which collectively constitute a horse, dog, or pigeon—remain unaltered, whether the animal has assumed a degraded or an elevated type of its specific form. An animal is adapted to its geographical area by the endowments of its conscious principle, of which element its corporeal structure is the mere instrument. Every animal reacts on the area which it inhabits; that reaction being, in fact, the final purpose for which the animal was created.[2] . . . We must also look for the explanation of the dependence of specific animal forms on their appropriate geographical areas, not in the mere adaptation of their corporeal structure, but more immediately in their specific instinctive consciousness. When a species ceases to exist, we must consider its disappearance as the result, not of a mere struggle for existence with other animal forms or with cosmical conditions, nor of insufficient adaptivity to such extent of altered conditions of life as its specific endowments admit, but as the more or less direct result of the law impressed upon its instinctive consciousness, in virtue of which it must cease to exist, when no longer supplied with the conditions on which its activity and faculties may be exercised through the instrumentality of its corporeal vehicle. As the instinctive consciousness, the corporeal structure, and the geographical area of an animal species are three co-ordinate elements in its specific constitution, it is evident that any one of these elements can only be efficiently investigated when the other two elements are fully represented in the question."[3]

Upon the subject of "the origin of species by means of natural selection, or the preservation of favoured

[1] "The Origin of Species," by Charles Darwin, M.A., F.R.S., &c. London, 1869, pp. 48 and 49.

[2] Mr. Darwin himself furnishes an important example of this in his work, "On the Earth Worm," which he shows to be largely instrumental in the production of soil.

The presence or absence of plants in a locality increases or diminishes the amount of moisture in the air, and so, to a large extent, determines climate.

[3] "Lectures on the Dignity of the Human Body," by John Goodsir, F.R.S., Professor of Anatomy in the University of Edinburgh. ("Anatomical Memoirs," vol. i., pp. 208–214.)

races in the struggle for life," it may be useful to adduce the views of Mr. Herbert Spencer. Spencer to begin with was in favour of the Darwinian theory. He was the first to employ the phrase "survival of the fittest," a phrase invented by him to bolster up the theory and add to its comprehensiveness. He invented other phrases with a like end in view, but he abandoned them all as inadequate. From being an active supporter of the theory he became its active opponent.

Among the phrases invented by Mr. Spencer in support of Darwinism may be cited the following: (*a*) "the survival of the fittest" already referred to; (*b*) "the natural selection of favoured variations"; (*c*) "the inheritance of functionally produced modifications," &c. Mr. Spencer's phrases are unfortunately as obscure as Mr. Darwin's original phrase.

The late Duke of Argyll, in his work "Organic Evolution Cross-examined,"[1] with his usual dialectic skill and critical acumen sums up between Mr. Darwin and Mr. Spencer, as follows: (Mr. Spencer) "having first sought some shelter of authority under the words of the great prophet himself, he becomes more and more aggressive against the pretenders to his authority." "Nowadays," Mr. Spencer observes, "most naturalists are more Darwinian than Mr. Darwin himself." Continuing, "he compares their blindness respecting the insufficiency of natural selection with the blindness of naturalists to the facts of evolution before Mr. Darwin's book appeared. He marshals and reiterates the obvious considerations which prove that the development of animal forms must necessarily depend on an immense number and variety of adjusted changes in many different organs, all co-operating with each other, and nicely adapted to the improved functional actions in which they must all partake. He reduces to a numerical computation the practical impossibility of such changes occurring as the result of accident. He tells his opponents that the chances against any adequate readjustments fortuitously arising 'must be infinity to one.' But more than this: he not only repels the Darwinian factor as adequate by itself, but, advancing in his conclusions, he declares that it must be eliminated altogether. On further consideration he tells us that in his opinion it can have neither part nor lot in this matter. He insists that the correlated changes are so numerous and so remote that the greater part of them cannot be ascribed (even) in any degree to the mere selection of favourable variations."

A common charge may be preferred against both Mr. Darwin and Mr. Spencer as regards the nomenclature employed. They both deal in phrases which lack definiteness. They use words and terms in a new sense without sufficiently explaining the exact meaning to be attached to them. They dissociate them from their recognised connections, and employ them in unusual combinations, which are calculated at once to perplex and mislead. The perverse and lax use of language, although not suspected, is the stronghold of the majority of untenable theories. Mere phrase-making is not science, and the modern reader will do well to avail himself of every opportunity to prick and burst the delusive bubbles in which the phrase-makers habitually traffic. Of late years phrase-making has become a fashionable cult, and while the dilettanti in science are the chief offenders, not a few of the so-called philosophers, when they get into a tight place, take refuge in a crowd of unmeaning words, much in the same way that the cuttle-fish hurries off in the obscure aqueous cloud produced by the voluntary discharge of his ink-bag.

The natural selection of Mr. Darwin ignores a First Cause, and takes for granted but does not and cannot prove the existence of what is, practically, a secondary cause. Mr. Spencer makes this very clear. He says: "the words 'natural selection' do not express a cause in the physical sense." It is a mere "convenient figure of speech."

Natural selection is a phrase invented for a purpose, but the purpose, which is subversive of scientific accuracy, and, in some measure, of truth, is kept studiously in the background. Natural selection and artificial selection in the Darwinian sense have nothing in common. Artificial selection as apart from an intelligent selector, outside the thing selected, is a misnomer. Similarly, natural selection without a presiding intelligent First Cause outside plants and animals is a chimera, a mere aberrant fancy. If natural selection means anything it means, as already stated, God selection. The abstract term "Nature" means Nature's God, and natural selection while it ignores cannot get rid of the First Cause.

As I have already shown, plants and animals have no power of themselves or in themselves to select and perpetuate their good properties and qualities to the exclusion of their bad properties and qualities. Neither can a mechanical unintelligent environment do this. If, however, neither the plant nor animal nor their environments can select, it follows that selection, if it ever occurs, is made by an intelligent First Cause outside the things selected, and outside environment.

There is no getting away from this conclusion. It is not denied that plants and animals are endowed by their Creator with a selective power within limits, which makes them superior to their surroundings. Thus the secreting glands of animals select various substances from the blood (secretions) which differ in chemical composition, and which being taken from the blood at one point are added to it at another point. The excretory glands, in like manner, select and abstract from the blood waste products which they extrude from the body.

[1] London, 1898, pp. 15, 16, and 17.

Plants and animals, in a state of nature, select their pabulum, and, within limits, their habitats. They affect certain foods and eschew others. They protect themselves against externalities when these are inimical, such as climate, excess or want of heat, excess or want of moisture, and so on. This limited power of selection is part of the original equipment of plants and animals, and is conferred on them by their Creator at the outset to enable them to maintain their place in nature under the varying conditions to which they find themselves from time to time exposed.

Plants and animals are not mere automata. They are self directing up to a point, but they have no power of changing their forms and constitutions by endless modifications throughout the ages at the bidding of chance, or of converting themselves into practically new beings by what is virtually a process of evolution. Plants and animals are not manufactured out of each other, and chance variations are not perpetuated by hereditary descent to form new individuals. This would be subversive of the law and order which pervades nature. Plants and animals are original creations. They have and inherit fundamental endowments of which they cannot be deprived, and the endowments in question are never chance endowments. Plants and animals reproduce themselves, each after their kind. In this we have an adequate explanation of the prevalence and persistency of type.

Of late years the theory of the origin of species by means of natural selection has been confounded with the theory of evolution. They are, however, essentially distinct. The theory of evolution is comparatively an old theory brought into prominence by Lamarck, that of the origin of species by natural selection dating back only to 1858.

While Mr. Darwin's theory of the origin of species by means of natural selection gave a powerful impulse to the theory of evolution it by no means originated it. As a matter of fact, the theory of evolution is as old as philosophy itself.

From my particular standpoint, I regard evolution, in the inorganic kingdom, as the mere unfolding or opening out in orderly fashion in time and space of the predetermined details of the world of non-living matter. I further regard evolution, in the organic kingdom, as at most the equivalent of development in its relation to young or growing plants and animals, which are the descendants of types of pre-existing plants and animals, and which form part of a predetermined scheme. I do not believe that heterogeneity in the inorganic and organic kingdoms is ever the outcome of homogeneity. In other words, I discredit the assertion that the infinite variety of substances met with in the inorganic kingdom are the product of one simple substance, and that the bewildering array of plants and animals, all differing more or less from each other, are the outcome (by a process of evolution) of one kind of protoplasm identical in ultimate composition. There is no proof of absolute simplicity in anything, living or dead. As science advances, the trend is in the direction of heterogeneity and complexity rather than homogeneity and simplicity. As I believe in a Creator, a First Cause, and Design, I am forced to disbelieve in the origin of species by means of natural selection, which rejects all three.

It is not necessary to follow Mr. Darwin through his labyrinth of illustration. The principle of his contention is succinctly set forth in the brief passages given above.

The analogy (in the Darwinian sense) between artificial and natural selection on which Mr. Darwin's famous theory rests is not a strong one. In the one instance (artificial selection), intelligence of a high order is, admittedly, always present. In the other (natural selection), such intelligence is denied, and a First Cause and design ignored. Everything is left to chance. A mechanical utilitarianism is credited with what is and what shall be. As a matter of fact, however, no actual proof of natural selection, as an entity, can be adduced.

It has been satisfactorily proved that while mere varieties if crossed are fertile, distinct species when crossed are infertile. Thus the several varieties of pigeons are fertile with each other, while the progeny of different species of birds are infertile. The same holds true of sheep and goats, of horses and asses, &c.

A persistent attempt has been made of late years to show that there is no limit to the modifications occurring in plants and animals, and that the said modifications are the main factors in the production of species, and in making plants and animals what they are. As explained, practically unlimited modification and unlimited time are claimed for the production of species. The Ancona breed of sheep with short legs, and a human family having in many instances six fingers and toes on each hand and foot, are cited as important modifications which may be made permanent by interbreeding. This is regarded as a proof that modifications, if allowed to accumulate over vast intervals of time, will be rendered permanent and produce new species and virtually new beings. The modifications referred to are assumed to be the first departures towards practically endless changes, in many cases very minute but always very persistent. Of these unlimited modifications in endless time there is, however, no direct or satisfactory proof. The short-legged sheep and the six-fingered and toed people would, if left to themselves, undoubtedly revert to their original types. They are at best sports or varieties. Mere length of limb or an extra digit do not materially affect their position as sheep or as human beings. The rule seems to be that plants and

animals vary within limits, but that in both there is a well-marked and persistent tendency to revert or breed back to primal types.

Mere varieties of plants and animals appear and disappear in time and space, but do not affect the stability and permanency of so-called types. Cultivated plants, if neglected, degenerate and breed back, and the same holds true of pampered domestic animals. This tendency to, and power of, reversion shows pretty conclusively that modifications which result in temporary varieties do not necessarily produce species.

It has been well pointed out that the Ancona or short-legged breed of sheep, and the people with six fingers and toes, *were fertile amongst themselves*, and that we cannot quote the results of *artificial* selection as accounting for the origin of species by *natural* selection. Artificial and natural selection are not identical, and this is the crux of the whole matter.

Mr. Darwin and his followers endeavour to evade this difficulty. They say, "Not only is it not proved that all species give rise to hybrids infertile *per se*, but there is much reason to believe that, in crossing, species exhibit every gradation from perfect sterility to perfect fertility." The rejoinder is obvious. If infertility be a result of crossing true species such as the horse and ass, and this is on all hands admitted, fertility is a proof of mere varieties as opposed to species.

In this connection Mr. Darwin says: "First crosses between forms known to be varieties or sufficiently alike to be considered as varieties, and their mongrel offspring, are very generally, but not quite universally, fertile. Nor is this nearly general and perfect fertility surprising, when we remember how liable we are to argue in a circle with respect to varieties in a state of nature." He also states that certain plants are more fertile with the pollen of another species than with their own, and Mr. Huxley avers that there are certain *fuci* whose male element will fertilise the ovule of a plant of distinct species, while the males of the latter species are ineffective with the females of the first. The question of course here arises, were the subjects under consideration species or varieties? It may very well be that the so-called species were neither typical nor permanent, and were not deserving of a place in a really scientific classification. Besides, if species are the outcome of endless modification in endless time, and if the great races of plants and animals are the result of perpetual changes extending over long periods, and plants and animals merge into each other by insensible gradations, there is no halting or fixed point, and no need or excuse for attempting to define species or indeed to attempt classification of any kind. All classification proceeds on the supposition that plants and animals as they exist in time and space possess characteristics of form, function, reproduction, &c. It is hopeless to attempt to define or set limits to a living, ever-changing, mobile, fluctuating mass, which is never two seconds the same; but this is the impossible task before us if we regard plants and animals as infinitely unstable, which Mr. Darwin and his followers do. Classification proceeds, and properly, on a well-founded belief that plants and animals characteristically differ, and are divisible into classes, orders, families, genera, &c. Classification can only proceed on the basis of types. The types admit of variation up to a point, but the variation is corrected by a persistent tendency to breed back. Varieties and types co-exist: they are not destructive of each other. It is quite possible that while plants and animals may, with considerable truth, be divided into classes, orders, families, and genera, they cannot consistently or truthfully be divided into species; the so-called species, in many cases, being mere varieties.

Mr. Darwin and his supporters have striven to show that there is in nature a process which inevitably leads to the formation of species, provided sufficient (practically unlimited) time be allowed. They aver that the accumulation of trifling accidental variations and useful modifications extending over untold ages produces in time virtually new and perfect beings.

Reasoning out this hypothesis, the more advanced followers of Mr. Darwin do not hesitate to describe all the varieties of living things, including man, as the results of development from some primordial germ: and Mr. Darwin himself, in his work on the "Descent of Man," lays great stress on the occurrence of homologous structures in man and the lower animals, as well as on the development in man of rudimentary structures, which are either absolutely useless to their possessor, or of very slight service indeed, but which appear to serve as an index to the various stages through which the human species has passed in its progress upwards from lower forms of life. Mr. Wallace, however, sees in the production of man the intervention of an external will. He remarks "that the lowest types of savages are in possession of a brain, and of capacities far beyond any use to which they could apply them in their present condition, and that therefore they could not have been evolved from the mere necessities of their environments."

Professor Huxley was also of opinion that the Darwinian hypothesis required modification.

No doubt the Darwinian theory of descent has a fascination, especially for younger minds. It is simple in conception. It practically says: Given a living primordial germ, everything (plant and animal) proceeds therefrom by variation in the fulness of time.

This is readily understood, but there is one apparently insurmountable difficulty. The primordial germ itself has to be accounted for. Whence comes it? An act of creation is necessary for its production. It can only be the outcome of intelligence and a First Cause.

As regards the existence of homologous structures in man and the lower animals, and of rudimentary and apparently useless structures in man himself, it need only be said that they are proofs, not of endless modifications, but of a recurrence of fundamental or primal types, in whole or in part. During the development of plants and animals it not unfrequently happens that old parts shrink or disappear, and are succeeded by new and different parts.

The existence of law and order in the inorganic and organic kingdoms necessitates not only a sequence of events, but also a sequence of forms. No marvel, then, that crystalline and other simple shapes reappear in plants and animals, and that traces of pre-existing types crop up in the latest and most highly developed forms up to man. Plants are not wholly separated from crystals, or animals from plants. The scheme of creation is that of a conditioned continuous whole, but not in the sense that one thing is directly evolved out of, or manufactured from, another thing. Creation is to be regarded as a whole, in the sense that plants and animals are arranged as an ascending series, and are, within limits, independent of each other. There are prevailing types whose boundaries are well defined, the one beginning where, in a sense, the other leaves off, but which nevertheless do not run into each other and so become continuous. If there had been actual continuity of types by modification and transmutation, the balance between rudimentary and highly complex types would have been seriously disturbed, if not wholly destroyed. There would have been a gradual disappearance of the elementary primitive forms in favour of the highly differentiated latter-day forms. In other words, if the complex forms are manufactured directly or indirectly out of the simple forms, it follows that the stock of simple forms would decrease in proportion as the stock of complex forms increases. There is, however, no proof of such decrease and increase. On the contrary, the simple forms appear in their millions, and are as numerous to-day as they were at the beginning of the present order of things. Similarly, the complex forms are not indefinitely augmented. This means that the simple and complex forms, and, by implication, the intermediate forms, exist side by side and have always done so, and have their limits in time and space. Their boundaries are, so to speak, set, and to each the fiat has gone forth, "thus far and no farther."

Those who believe in spontaneous generation and the origin of species by means of natural selection will no doubt attempt to get over this difficulty by saying that the rudimentary forms are being continually reproduced; but the power to reproduce, and to reproduce themselves only, implies the creative act of an intelligent Being: it implies the power to form and maintain types, and affords no support to modification and variation as main factors in the production of future and more complex plants and animals. On the power of reproduction depends the continuance of the great races of plants and animals. Without it they would cease to exist after the first generation.

This difficulty is not removed by saying, as is sometimes done, that at a period in the infinitely remote past a living germ was accidentally formed from non-living inorganic matter by a lucky concatenation of favourable circumstances, and that from it, by means of practically endless modification and variation, all plants and animals up to man have had their being. To concede such a contention is to give the situation away. All such views are founded on colossal assumptions, and scarcely deserve serious attention.

The truth of the theory of types seems proved by their persistency, and by the fact that animals of different species are for the most part, or altogether, barren. As an example of persistency, man himself may be quoted. He has not materially changed for several thousand years. The five great types of the human race were as well marked 5000 or 6000 years ago as they are at the present day.[1] Of course 5000 or 6000 years is a short time in the history of the world, but it should have considerable significance in the histories of plants and animals. If plants and animals can persist for thousands of years without change, it is not a little rash to assume that they are subject to infinite modifications; the more especially as these modifications cannot continuously be traced either in the geological record, or in plants and animals as they exist on the earth at present. The missing links, as they are called, are numerous and important, and, until they can be supplied, the theory of the origin of species by means of natural selection cannot be seriously entertained.[2]

[1] "Naturalists and ethnographers divide mankind into several distinct varieties, or races. Cuvier refers them all to three, Pritchard enumerates seven, Agassiz eight, Pickering describes eleven. One of the common classifications is that of Blumenbach, who makes five races: the *Caucasian* or white race, to which belong the greater part of the European nations and those of Western Asia; the *Mongolian*, or yellow race, occupying Tartary, China, Japan, &c.; the *Ethiopian*, or negro race, occupying most of Africa (except the north), Australia, Papua, and other Pacific Islands; the *American*, or red race, comprising the Indians of North and South America; and the *Malayan*, or brown race, which occupies the islands of the Indian Archipelago, &c. Many recent writers classify the Malay and American races as branches of the Mongolian" (Webster).

[2] If the theory of the origin of species by means of natural selection cannot explain the existence of the more stable typical forms of plants and animals, and of the varieties to which they occasionally give rise in the organic kingdom, it may be taken for granted that the theory will

Mr. Huxley in a speech at the anniversary dinner of the Royal Society in 1894 gave his final opinion of Mr. Darwin's "Origin of Species by Means of Natural Selection" in these words: "The views which were propounded by Mr. Darwin thirty-four years ago may be understood hereafter as constituting an epoch in the intellectual history of the human race. They will modify the whole system of our thought and opinion, our most intimate convictions. But I do not know, and I do not think anybody knows, whether the particular views which he held will be hereafter fortified by the experience of the ages that come after us." Mr. Huxley agreed with Mr. Darwin on the general question of evolution; he agreed with him and Mr. Herbert Spencer on "the survival of the fittest" as the means of pruning away the least improved individuals of a species; but he did not agree with Mr. Darwin as to the adequacy of the cause assigned by the latter for the beneficial variations on which the survival of the fittest operates. Mr. Wallace, while accepting evolution, and also recognising natural selection as the cause of a great part of the developments which have occurred, has maintained that "another part can only be accounted for by supposing the intervention of intelligence and intention." [1]

Mr. Darwin, it should be stated, did not attempt to account for the origin of the simple living forms from which he supposed all plants and animals ultimately proceeded. These he took for granted and postulated. Neither did he commit himself to the doctrine of spontaneous generation. The latter has been added to and grafted on his theory by his followers, who felt that a hypothesis which seeks to explain so much by purely mechanical adaptations, as apart from a First Cause and design, required to be supplemented by a purely mechanical origin of living things in which what is designated "a miraculous interference" took no part. They felt that if the accidental variation and modification of living things were purely mechanical and required no First Cause, no design, and no supervision, the first appearance of living things on the earth could, with equal propriety and truth, be referred to similar mechanical processes and arrangements. If a First Cause was not necessary to the variation and modification of plants and animals, neither was it, in their opinion, necessary to the first appearance of plants and animals on the earth.

Professor Haeckel, of Jena, is at once the most learned and advanced exponent of the spontaneous generation theory. He says: "The homogeneous, viscid, plasma substance, which singly and alone formed the bodies of the first organisms, and even at this day quite alone forms them in the case of the *monera*, or simplest amœbic forms, is analogous to the tenacious and viscid planetary substance which contains the elements and substance of the young earth, as well as of the other glowing world bodies. In both cases the form of the creation happened, not through the capricious interference of a personal Creator, but through the original power of matter fashioning itself. Attraction and repulsion, centripetal force and centrifugal force, condensation and rarefaction of the material particles, are the only creative powers, which at this point lay the foundations of the complicated structure of creation." [2]

signally fail to explain the existence of inorganic bodies, and the changes and movements which occur in them. An attempt has, however, been made, unsuccessfully it appears to me, to graft on the theory of "natural selection" as applied to supposed changes occurring in the organic kingdom to supposed analogous changes occurring in the organic one. Thus, Professor G. H. Darwin, of Cambridge, by what is practically a misuse of language, and what many will regard as straining of facts, says:—

"The fundamental idea in the theory of natural selection is the persistence of those types of life which are adapted to their surrounding conditions, and the elimination by extermination of ill-adapted types. The struggle for life amongst forms possessing a greater or less degree of adaptation to slowly varying conditions is held to explain the gradual transmutation of species. Although a different phraseology is used when we speak of the physical world, yet the idea is essentially the same. . . . Although inanimate matter moves under the action of forces which are incomparably simpler than those governing living beings, yet the problems of the physicist and the astronomer are scarcely less complex than those which present themselves to the biologist. . . . In the world of life the naturalist describes those forms which persist as species; similarly the physicist speaks of stable configuration or modes of motion of matter. The idea at the base of all these conceptions is that of stability, or the power of resisting disintegration. In other words, the degree of persistence or permanence of a species, of a configuration of matter, depends on the perfection of its adaptation to its surrounding conditions. . . . The physicist, like the biologist and the historian, watches the effect of slowly varying external conditions; he sees the quality of persistence or stability gradually decaying until it vanishes, when there ensues what is called, in politics, a revolution. . . .

"These considerations lead me to express a doubt whether biologists have been correct in looking for continuous transformation of species. Judging by analogy, we should rather expect to find slight continuous changes occurring during a long period of time, followed by a somewhat sudden transformation into a new species, or by rapid extinction. However this may be, when the stability of a mode of motion vanishes, the physicist either finds that it is replaced by a new persistent type of motion adapted to the changed conditions, or perhaps that no such transformation is possible, and that the mode of motion has become extinct. . . . The time-scale in the transmutation of species of animals is furnished by the geological record, although it is not possible to translate that record into years. As we shall see hereafter, the time needed for a change of type in atoms and molecules may be measured by millionths of a second, while in the history of the stars continuous changes may occupy millions of years. Notwithstanding this gigantic contrast in speed, yet the process involved seems to be essentially the same. . . . The study of stability and instability then furnishes the problems which the physicist and biologist alike attempt to solve. The two classes of problems differ principally in the fact that the conditions of the world of life are so incomparably more intricate than those of the world of matter that the biologist is compelled to abandon the attempt to determine the absolute amount of the influence of the various causes which have affected the existence of species. His conclusions are merely qualitative and general, and he is almost universally compelled to refrain from asserting, even in general terms, what are the reasons which have rendered one form of animal life stable and persistent, and another unstable and evanescent. On the other hand, the physicist, as a general rule, does not rest satisfied unless he obtains a quantitative estimate of various causes and effects on the systems of matter which he discusses. . . . Natural selection may seem, at first sight, as remote as the poles asunder from the ideas of the alchemist, yet dissociation and transmutation depend on the instability and regained stability of the atom, and the survival of the stable atom depends on the principle of natural selection." (*Vide* Professor G. H. Darwin's address as President of the British Association, delivered at Capetown, South Africa, August 15, 1905.)

[1] "Doubts about Darwinism." London, 1903.

[2] Haeckel, "Natürliche Schöpfungsgeschichte," p. 266. Berlin, 1868.

Later, in his work entitled "The Riddle of the Universe," published in 1899, he adds: "We are justified in supposing that thousands of these planets are in a similar stage of development to that of our earth—that is, they have arrived at a period when the temperature of the surface lies between the freezing and boiling point of water, and so permits the existence of water in its liquid condition. That makes it possible that carbon has entered into the same complex combinations on those planets as it has done on our earth, and that from its nitrogenous compounds protoplasm has been evolved—that wonderful substance which alone, as far as our knowledge goes, is the possessor of organic life. The monera (for instance, chromacea and bacteria), which consist only of this primitive protoplasm, and which arise by spontaneous generation from these inorganic nitro-carbonates, may thus have entered upon the same course of evolution on many other planets as on our own; first of all, living cells of the simplest character would be formed from their heterogeneous protoplasmic body by the separation of an inner nucleus from the outer cell-body."

When Haeckel wrote the "History of Creation," he believed that a very remarkable discovery had recently been made, which enabled him to say that protoplasm was still being produced. Mr. Huxley had fished up from the deep sea a mass of something which he believed to be protoplasm, and to which he had given the name of *Bathybius haeckelii*, in honour of its having appeared so opportunely for Haeckel's views. But on further investigation Bathybius did not bear out the hopes that had been entertained; and Mr. Huxley himself appears to have given it up altogether. So far as known, it is doubtful whether it is a mineral substance in a gelatinous state, or, if it is protoplasm at all, it is protoplasm produced from the decay of some low organisms. At any rate, it cannot be counted on as evidence of the present production of protoplasm.[1]

The accounts given by Professor Haeckel of spontaneous generation and protoplasm are by no means reassuring or satisfactory. His generalisation as to the fundamental resemblances between inorganic and organic bodies has much to recommend it, and is no doubt founded on fact. He, however, misses the mark when he attributes them solely to the operation of mechanical forces and laws as apart from a First Cause and design. Professor Haeckel endeavours to strengthen his position by a reference to the advances made by modern chemistry, but in so doing he is bound to acknowledge the shortcomings of this subtle and far-reaching science. He writes: "Not fifty years ago all chemists maintained that we were unable to produce artificially in our laboratories any complicated combination of carbon, or so-called 'organic combination.' The mystic 'vital force' alone was supposed to be able to produce these combinations. When, therefore, in 1828, Wöhler, in Göttingen, for the first time refuted this dogma, and exhibited pure 'organic' urea obtained in an artificial manner from a purely inorganic body (cyanate of ammonium), it caused the greatest surprise and astonishment. Since then we have succeeded in producing in our laboratories a great variety of similar 'organic' combinations of carbon by purely artificial means—for example, alcohol, acetic acid, formic acid. Indeed, many exceedingly complicated combinations of carbon are now artificially produced, so that there is every likelihood, sooner or later, of our producing artificially the most complicated, and at the same time the most important of all, namely, the albuminous combinations, or plasma-bodies."

The following pertinent question has been put by a recent writer in this connection. He asks, and not unnaturally, "Can a living body be made of urea and alcohol, formic acid, and any other product of German laboratories?" A reply in the negative may unhesitatingly be given.

In striking contrast to the purely chemico-mechanical views of life and organisation advocated by Professor Haeckel are those of Lord Kelvin, then the greatest of living physicists, expressed at a medical function at St. George's Hospital, London (October 28, 1904).[2] Addressing an assemblage of young medical men he said: "The modern medical man must be a scientific man, and, what is more, he must be a philosopher. The fundamental studies of medicine are of a strictly materialistic kind, but they belong to a different world from the world which constitutes their main subject—the world of life. Let it not be imagined that any hocus-pocus of electricity or viscous fluids will make a living cell. Splendid and interesting work has recently been done in what was formerly called organic chemistry, a great French chemist taking the lead. This is not the occasion for a lecture on the borderland between what is called organic and what is called inorganic; but it is interesting to know that materials belonging to the general class of foodstuffs, such as sugar, and what might be also called a foodstuff, alcohol, can be made out of the chemical elements. But let not youthful minds be dazzled by the imaginings of the daily newspapers that because Berthelot and others have thus made foodstuffs they can make living things, or that there is any prospect of a process being found in any laboratory for making a living thing, whether the minutest germ of bacteriology or anything smaller or greater. There is an absolute distinction between crystals and cells. Anything that crystallises may be made by the chemist. Nothing approaching to the cell of a living creature has ever yet been made. The general result of an enormous amount of exceedingly intricate and thorough-going investigation by Huxley and Hooker and others of the present age, and by some of their predecessors in both the nine-

[1] "Doubts about Darwinism." London, 1903.

[2] Vide *Nature* for November 3, 1904.

teenth and eighteenth centuries, is that no artificial process whatever can make living matter out of dead. This is vastly beyond the subject of the chemical laboratory, vastly beyond my own subject of physics or of electricity—beyond it in depth of scientific significance and in human interest."

§ 215. Professor Haeckel an Advanced Exponent of the Darwinian Theory.

Professor Haeckel is, on the whole, the most advanced exponent of Mr. Darwin's views. He attaches greater importance to them than any other living writer. He places the theory of natural selection and descent on a par with the law of gravitation, and regards the former as even of greater value. Few will agree with him in this inflated estimate, seeing there are endless proofs of the operation of gravitation, and none either of natural selection or descent in the Darwinian sense.

Professor Haeckel is a believer in, and advocate of, spontaneous generation. He regards matter and force as eternal entities—force being a property of matter.[1] He is a monist pure and simple. He scouts the idea of living matter as a thing *per se*, and considers it the outcome of dead matter. In like manner he extols physical force and denies the existence of vital force. With him there is a body, but no spirit or soul, no Creator, no immortality. The dualistic idea of mind and matter he altogether ignores and ridicules. For him there is at the outset only dead matter and physical force; the matter being self-creating, self-forming, and self-regulating.

According to him primal matter and force under certain circumstances evolve by spontaneous generation the lowest plants and animals; the latter in turn evolving during countless ages the higher and highest plants and animals up to man. With him there are no separate creations of plants and animals—no types which have an independent origin, and which persist and retain their independence in time and space.

All plants and animals, in his opinion, are related to each other by direct descent and in an unbroken series; the lower plants and animals being the progenitors of the higher plants and animals—there being in the case of the higher animals blood-relationships. According to him all plants and animals are referable to one or at most a few primordial or central forms of which all the others are derivations. The differentiation in plants and animals is a mere question of dividing and branching, hence his numerous genealogical tables and charts. With him everything is, and has always been, in a state of flux. There is no fixity or permanence, and no boundaries between plants and animals and parts thereof. Everything runs into and merges into every other thing by insensible gradations. There are endless modifications in plants and animals from the lowest to the highest, but no Creator or separate creations—no Designer and no limits whereby plants and animals can be defined. He makes no allowance for breaks in the plant and animal series, for deteriorations, and for cataclysms, when certain plants and animals become fewer, disappear, and are lost. In his eyes there is a continuous advance or evolution from lower to higher forms up to the monkeys and, through them, to man. He acknowledges no miraculous interference at the outset, and no controlling power subsequently, outside plants and animals themselves. He contends that dead matter forms and regulates itself and assumes life *de novo*; the living thing, plant and animal alike, working out its own destiny unaided. His scheme of the inorganic and organic kingdoms is wholly mechanical, and, to a large extent, accidental. He eschews spirit, intelligence, and design as factors in the cosmos. He is opposed to Linnæus, Cuvier, Agassiz, and others who believe in a Creator and creations, and who maintain that plants and animals are more or less permanent and can be classified. The following are his pronouncements: "The real matter of dissension in the contest carried on by naturalists as to the origin of organisms, their creation and development, lies in the conceptions which are entertained about the *nature of species*.[2] Naturalists either agree with Linnæus, and

[1] The following is briefly Professor Haeckel's creed: "Natural science teaches that matter is eternal and imperishable. . . . The coming into existence of a natural body—for example, of a crystal, a fungus, an infusorium—depends merely upon the different particles, which had before existed in a certain form or combination, assuming a new form or combination in consequence of changed conditions of existence. . . . All natural bodies which are known to us are equally animated; the distinction which has been made between animate and inanimate bodies does not exist. . . . This unity of all nature, the animating of all matter, the impartiality of mental power and corporal substance, Goethe has asserted in the words, 'Matter can never exist and be active without mind, nor can mind without matter.' The fundamental idea, which must necessarily lie at the bottom of all natural theories of development, is that of a *gradual development of all (even the most perfect) organisms* out of a single, or out of a very few, quite simple and quite imperfect original beings, which came into existence, not by supernatural creation, but by *spontaneous generation* or archigony, out of inorganic matter." ("The History of Creation," by Ernst Haeckel, pp. 8, 22, 23, 4th edition. London, 1899.)

[2] A question of very considerable importance emerges here. Is it wise or well to attach so much value and significance to species as such, seeing botanists and zoologists are perpetually wrangling as to what constitutes a species? Scarcely any two naturalists can be found to agree on the subject, and no term employed in science has been more abused, or used with greater laxity. Its exact meaning certainly cannot be defined, and what one authority regards as a species another regards as a mere variety. If, however, naturalists cannot agree as to what constitutes a true species, it follows that "species" ought not to form the pivot on which the momentous questions of the origin of organisms, their creation, and development should revolve. It should not constitute the battle-ground on which those great issues are to be settled. If real progress is to be made in science the position of opposing camps must be known, and, above all, the bone of contention must be in full view and its properties and qualities accurately estimated by both sides. No finding of any value can be arrived at concerning a thing which, in a sense, has no existence. Professor Haeckel, who assigns "species" such a central position in the histories of plants and animals, nevertheless writes:—"No naturalist can answer the question as to what is in reality a genuine or good species (bona species); yet every systematic naturalist uses this expression every day, and whole libraries have been written on the question as to whether this or that observed form is a species or a variety, whether it is a really good or a bad species" ("The History of Creation," 4th edition, vol. i., p. 305. London, 1899). Mr. Darwin recognises the lax views

look upon the different species as distinct forms of creation, independent of one another, or they assume with Darwin their blood-relationship. If we share Linnæus's view that the different organic species came into existence independently—that they have no blood-relationship—we are forced to admit a supernatural creation, and must either suppose that every single organic individual was a special act of creation (to which surely no naturalist will agree), or we must derive all individuals of every species from a single individual, or from a single pair, which did not arise in a natural manner, but was called into being by command of a Creator. In so doing, however, we turn aside from the safe domain of a rational knowledge of nature, and take refuge in the mythological belief in miracles.

"If, on the other hand, with Darwin, we refer the similarity of form of the different species to real blood-relationship, we must consider all the different species of animals and plants as the altered descendants of one of a few most simple original forms. Viewed in this way, the natural system of organisms (that is, their tree-like and branching arrangement and division into classes, orders, families, genera, and species) acquires the significance of a real genealogical tree, whose root is formed by those original archaic forms which have long since disappeared. But a truly natural and consistent view of organisms can assume no supernatural act of creation for even those simplest original forms, but only a coming into existence by *spontaneous generation* (archigony, or *generatio spontanea*). From Darwin's view of the nature of species, we arrive therefore at a *natural theory of development;* but from Linnæus's conception of the idea of species, we must assume a *supernatural dogma of creation.* Cuvier in his conception and definition of the idea of species agreed on the whole with Linnæus, and shared also his belief in an independent creation of individual species. Cuvier considered their immutability of such importance that he was led to the foolish assertion, 'The immutability of species is a necessary condition of the existence of scientific natural history.' . . . He made an attempt to give a more exact and, for systematic practice, a more useful definition, in the following words: 'All those individual animals and plants belong to one species which can be proved to be either descended from one another, or from common ancestors, or which are as similar to these as the latter are among themselves.' . . . Cuvier is the most formidable opponent to the Theory of Descent and the monistic conception of nature. One of the many and great merits of Cuvier is that he stands forth as the founder of comparative anatomy. He also greatly advanced the science of palæontology. . . . Linnæus had arranged all animals in a single series, which he divided into six classes—two classes of Invertebrate, and four classes of Vertebrate animals. He distinguished these artificially, according to the nature of their blood and heart. Cuvier, on the other hand, showed that in the animal kingdom there were four great natural divisions to be distinguished, which he termed Principal Forms, or General Plans, or Branches of the animal kingdom (Embranchments), namely: 1. The Vertebrate animals (Vertebrata); 2. The Articulate animals (Articulata); 3. The Molluscous animals (Mollusca); and 4. The Radiate animals (Radiata). He further demonstrated that in each of these four branches a peculiar plan of structure or type was discernible, distinguishing each branch from the three others. . . . He showed that in the development of animals, also, four different main forms (or types) must be distinguished. These correspond with the four plans of structure in animals, which Cuvier distinguished on the ground of comparative anatomy. . . . Neither he, who arrived at the distinction of the four animal types or principal forms through the history of the individual development (embryology), nor Cuvier, who arrived at the same conclusion by means of comparative anatomy, recognised the true cause of this difference. This is disclosed to us by the Theory of Descent. . . . All petrified or fossil remains and impressions tell us of the forms and structure of such animals and plants as are either the progenitors and ancestors of the present living organisms, or they are the representatives of extinct collateral lines, which, together with the present living organisms, branched off from a common stem. . . . Agassiz, in an essay on classification, not only discusses the natural series of organisms, and the different attempts of naturalists at classification, but also all the general biological phenomena which have reference to it. The history of the development of organisms, both the embryonal and the palæontological, comparative anatomy, the general economy of nature, the geographical and topographical distribution of animals and plants—in short, almost all the general phenomena of organic nature—are dealt with and explained in a sense and from a point of view which is thoroughly opposed to that of Darwin. While Darwin's chief merit lies in the fact that he demonstrates *natural* causes for the coming into existence of animal and vegetable species, and thereby establishes the mechanical or monistic view of the universe as regards this most difficult branch of the history of creation, Agassiz, on the contrary, strives to exclude every mechanical hypothesis from the subject, and to put the *supernatural* interference of a personal Creator in the place of the natural forces of matter; consequently, to establish a thoroughly teleological or dualistic view of the universe."[1]

entertained regarding species. He says: "No one definition has as yet satisfied all naturalists; yet every naturalist knows vaguely what he means when he speaks of a species. Generally the term includes the unknown element of a distinct act of creation. The term 'variety' is almost equally difficult to define; but here community of descent is almost universally implied, though it can rarely be proved."

Everything considered, it seems unphilosophical to attach so much importance to species, which is, at best, only one of several arbitrary divisions. The classification of plants and animals can never be an exact science, and the separation of them into branches, classes, orders, families, genera, and species is at most provisional.

[1] "The History of Creation, or the Development of the Earth and its Inhabitants by the Action of Natural Causes." London, 1899.

Philosophers and naturalists are ranged in two opposing camps; one side upholds the spontaneous generation, mechanical, or monistic view of the universe—the other the creationist, teleological, or dualistic view. The great German philosopher, Immanuel Kant, in his younger days supported the former view, but in his later days and riper judgment the latter one. He thus expresses himself:[1] "It is quite certain that we cannot become sufficiently acquainted with organised creatures and their hidden potentialities by aid of purely mechanical natural principles, much less can we explain them; and this is so certain, that we may boldly assert that it is absurd for man even to conceive such an idea, or to hope that a Newton may one day arise able to make the production of a blade of grass comprehensible, according to natural laws ordained by no intention; such an insight we must absolutely deny to man."

As regards the monistic and dualistic theories it is safe to assert that both contain truth, but that neither of them contains the whole truth. The monist is not entitled to say that everything in the universe is mechanical; neither can the dualist affirm that mechanics are excluded. A First Cause, law, order, and design manifest themselves by mechanical and other arrangements alike in the inorganic and organic kingdoms. In this sense, and in this sense only, can the idea of oneness be arrived at. The Creator alone represents unity, and He influences everything, dead and living, and correlates and co-ordinates the one to the other in time and space. The spontaneous generation, mechanical theory cannot by itself account for the existence of plants and animals on the earth; neither can the vital, dualistic theory offer a solution as apart from the inorganic elements which enter into plants and animals and the mechanical laws which govern these elements. There is clearly an interdependence between inorganic and organic matter and between physical, vital, and mental force. The key to the situation is in the hands of the great "I am" Who made, sustains, and regulates the universe. There is no getting behind a First Cause and design, and the law and order which a First Cause and design imply.

In connection with these quotations from Professor Haeckel it is to be observed that he does not attempt to explain the origin of life. He evades this most important problem, and takes refuge in spontaneous generation —spontaneous generation, after the most careful experiments oft repeated, having been proved to be an impossible doctrine. Similarly, Mr. Darwin takes life for granted. He only seeks to account for what he regards as mechanical modifications and adaptations in existing living plants and animals; these having, he maintains, an upward evolutionary trend. If, however, Professor Haeckel and Mr. Darwin cannot account for the origin of life and for the one or few primal forms from which they assert the higher and highest plants and animals proceed in unbroken continuity, then all they have to say regarding modifications, differentiations, divisions, and branchings in plants and animals must be received with the extreme of caution. They cannot speak with authority as to vital changes which occur in plants and animals if they are wholly ignorant of the nature and source of life. As a matter of fact they have to postulate for the production of the higher plants and animals not only the existence (unaccounted for) of the lowest plants and animals but also endless modifications in them throughout untold ages.[2]

They have also to claim an unbroken continuity of existence for both, which geology and palæontology and history do not sanction. They cannot account for the numerous missing links which of themselves form an insurmountable difficulty; neither can they explain the extraordinary progress and persistency of certain plants and animals and the deterioration and disappearance of others. They give a free rein to chance in the production of living things, and exalt the creature above the Creator. They claim law and order in the absence of a Lawgiver and First Cause. They seek to evolve differentiated complex plants and animals from what they regard as undifferentiated simple homogeneous protoplasm by a self-directive process which they assume but cannot prove. They cannot satisfactorily explain any one of the numerous attributes of life, sensation, consciousness, volition, mind, &c. They cannot account for reproduction, development, growth, the origin of the sense organs, organs of locomotion, and organs generally. They have no explanation to give of the rise and progress of the several systems which characterise the higher animals—the muscular, osseous, glandular, digestive, absorbing, secreting, respiratory, vascular, nervous, and other systems. They fail to account for the peculiar relations which obtain between the inorganic and organic kingdoms. Their theories are based on assumption pure and simple. All they say is to be taken in faith. The arguments which they bring against a personal Creator and miracles apply with greater force against themselves. They take for granted the existence of matter and force in the world, and the accidental assumption of life. Can any or all of these be regarded as less than miraculous? They claim law and order and the power of evolving for the cosmos. Can these be accounted for apart from a First Cause, intelligence, and design?

[1] "Of the Necessary Subordination of the Mechanical to the Teleological Principle in the Explanation of a Thing as a Purpose or Object of Nature."

[2] "The Doctrine of Filiation, Transmutation, or Theory of Descent affirms that all organisms (namely, all species of animals, all species of plants, which ever existed or still exist on the earth) are derived from one single, or from a few simple original forms, and that they have slowly developed from them by a natural course of gradual change." ("The History of Creation," by Ernst Haeckel, p. 4, 4th edition. London, 1899.)

They hand over to an unknown, unreasoning, unintelligent power all the affairs of the universe: they confide the destinies of plants and animals to a principle which they can neither define nor demonstrate, and which can have no existence apart from a Creator and Upholder: they seek to abolish the reign of law as a result of a First Cause, intelligence, and design, but they have nothing to offer in their place. They grope about in the dark for efficient causes and deliberately shut their eyes to such as lie on the surface. They are not content to take things as they find them and as approved by experience and history; they must needs go behind both, and seek an explanation in a fabulous antiquity of which experience and history form no part.

Modern men and women are asked to choose between what is practically chance, accident, anomaly, confusion, and flux, and a well-ordered state of things which has, there are good grounds for believing, existed from all time. There are initial difficulties of great magnitude connected with the doctrine that all plants and animals are the lineal descendants of homogeneous, undifferentiated protoplasm, however long the time allowed, and these difficulties become indefinitely increased when attempts are made to explain the attributes of the higher animals, such as sensation, consciousness, volition, memory, mind, &c. If the jelly speck of protoplasm contains or is under the control of the Creator, then, and only then, the results claimed are possible.

Professor Haeckel and Mr. Darwin endeavour to break down the argument for design and for types by, among other things, the existence of vestiges or rudimentary structures in the higher animals. They say that vestiges or rudimentary structures which perform no function in the animal economy are wholly subversive of the idea of teleology or the doctrine of final causes. They maintain that if there are structures in living bodies which perform no function, then the structures which do perform definite functions are not special creations and are not means to ends. The argument is specious, but partial and inconclusive. Moreover, it cuts both ways. It is not certain whether the so-called vestiges are structures which have done their work in the individual or in the race and are deteriorating and disappearing; or structures which are in process of formation, and which are destined to supply a future want in the animal economy. This much seems certain—structures which are not constantly exercised become dwarfed and tend to disappear. Examples of this are found in the withered condition of paralysed limbs, and the shrivelled eyes of fishes which live in dark caverns. A distinction, moreover, is to be drawn between the disuse and partial or total disappearance of created structures, and the production of similar structures by use and externalities either accidentally or by voluntary efforts on the part of the organism which displays them. In the former case, the structure precedes the function: it is created to perform certain work and it is equal to the task assigned to it—there is an obvious adaptation of means to ends. In the latter case, there is, or may be, a felt or assumed want, but there are no means of gratifying it: the organism cannot call new structures into existence—it cannot grow or develop them again.

It is easy to understand how existing typical structures deteriorate or disappear from inactivity, or how by increased activity they are greatly developed and adapted to perform specific work to meet special requirements. In this case the type persists; the original shape and dimensions only being modified. The modified structures, so far from destroying the argument for design, strengthen it. The argument founded on disuse cannot apply to embryos or developing structures.

Professor Haeckel delivers himself in this connection as follows: "Of special interest among general biological phenomena are those which are quite irreconcilable with the usual supposition, that every organism is the product of a creative power, acting for a definite object. Nothing in this respect caused the earlier naturalists greater difficulty than the explanation of the so-called *rudimentary organs*—those parts in animals and vegetables which really have no function, which have no physiological importance, and yet exist in form. . . . Almost every organism, almost every animal and plant, possesses, besides the obviously useful arrangements of its organisation, other arrangements the purpose of which it is utterly impossible to make out. . . . It is precisely this widely spread and mysterious phenomenon of rudimentary organs, in regard to which all other attempts at explanation fail, which is perfectly explained, and indeed in the simplest and clearest way, by Mr. Darwin's *Theory of Inheritance and Adaptation*. . . . Some of the laws of inheritance and adaptation perfectly explain, in a mechanical way, the existence of rudimentary organs, so that we must look upon the appearance of such structures as an entirely natural process, arising from the *disuse of the organs*." [1]

It is convenient for Professor Haeckel, while endeavouring to buttress Mr. Darwin's mechanical arguments against a First Cause and design, to declare that rudimentary structures in plants and animals are subversive of teleology, and that there is no such thing as a general plan and predetermined "means to ends." The so-called rudiments, however, in my opinion, even more than the fully completed structures, proclaim design. All structures and organs, whatever their nature, are in the embryological stage rudimentary or imperfect. They are prepared before they are required, and this is the very essence of design. Only those parts that are of use are fully developed and

[1] "The History of Creation," by Ernst Haeckel, pp. 11, 12, and 16, 4th edition. London, 1899.

permanent. Development as a whole proceeds by suppressing or partly suppressing parts of the organism and building up others. No wonder, then, that parts, even in the highest plants and animals, appear as remnants or rudiments for which apparently there is no function, or which have already discharged their function, as in the shrunken thymus and thyroid glands of animals. The remnants or rudiments constitute the indices or boundary stones of a general plan wholly, or, in great measure, carried out. The remnants are never out of place in the general plan : it is a mere question of complete or partial development, or suppression or partial suppression of structures the work of which is completed in the individual, or in the vegetable or animal series. Nay more, and as showing that suppression or partial suppression of parts is necessary to the great scheme of creation as witnessed in plants and animals, it may be stated that differentiation or the division of labour in plants and animals is largely due to that principle. In fact the dwarfing or obliteration of one part and the development and growth of another part are the cause of every conceivable kind of modification in the structures and functions of plants and animals. No better examples of this principle can be furnished than are supplied by the travelling organs of animals. Here there is suppression, or part suppression, of important parts for a very obvious purpose. In the sea-mammals, as, for example, the seal, sea-lion, and walrus, the posterior extremities are dwarfed : in the whale there are the merest traces of them, and in the porpoise they are non-existent. But (and here comes the crux) the dwarfing and suppressing of the posterior extremities of the sea-mammals, for swimming purposes, do not make them rudiments in the ordinary sense, and furnish no argument against design. On the contrary, the modifications and suppressions in question supply the strongest possible evidence of design. That animals differing so remarkably in structure from the fish should, nevertheless, by the dwarfing and suppression of parts, be enabled to live on and in the water fills the mind with astonishment. The same is to be said of certain birds. In the ostrich, the emu, and apteryx, the wings are reduced to mere vestiges, and the legs greatly developed and strengthened. These birds are especially designed for running. The guillemot, marrot, dabchick, &c., have very small wings and fly seldom : they are intended mainly as divers. The wings of the penguin are mere rudiments, have no feathers, and are so small that the bird cannot fly out of, but only in, the water. In all these cases the most subtle adaptations of means to ends are apparent. The design comes out not in the development of organs but in their reduction and partial or complete suppression. No one who has studied the organs of locomotion can fail to perceive, that by adding to and taking from these structures at discretion, the very finest examples not only of design but also of art and utility are reached. The dwarfing of organs and parts of organs affords no proof whatever of the absence of a First Cause and design ; and the so-called rudimentary organs are, in many cases, quite as useful as the more highly developed ones.

The subject of the production, dwarfing, and suppressing of organs is second to none in importance from a teleological point of view. One of Mr. Darwin's chief difficulties in framing and upholding his theory of the origin of species by means of natural selection was the formation, *and in advance*, of the electric organs in fishes. These are large, heavy structures, and, during their formation, extending according to him over many generations, must have been absolutely useless and a great burden. His natural selection theory could only come in when the structures were completed and in working order. The kernel and keynote of his theory is *utility*, and consists in variations *useful* to the individual, which give it an advantage over its fellows in the struggle for life. The useful or advantageous side of his theory, however, can only come into operation when plants and animals and their several parts are completed. Mr. Darwin's theory, as indicated, wholly fails to explain or account for growing rudimentary structures which are prepared in advance and before they can be useful to the individual of which they form a part. The theory, in fact, fails both as regards rudimentary and fully developed plants and animals.

Reverting to modifications (reductions and expansions) in animals for the purposes of locomotion it should be stated that even the shapes of the bodies of animals proclaim design. The seal, sea-lion, and walrus are largely fish-shaped, and the porpoise and whale wholly so. The bodies of birds are made for cleaving the air, and for floating on and cleaving the water. The feet of quadrupeds are small and are adapted for travelling on land which furnishes support and a stable fulcrum for the forward leverage of the feet and limbs ; here there is a suppression of parts ; the feet of the horse affording the best example of a land animal, it having fewer digits than any other land animal. The feet of the otter and platypus are expanded and webbed. They are fitted for running and swimming. Here there is no dwarfing, but partial expansion. In the seal, sea-lion, and walrus there is part suppression and part expansion. The anterior extremities are enlarged, and the posterior extremities are dwarfed and their digits webbed so that they can be alternately spread out and closed to seize and let go the water as in the tail of the fish. In the whale, as pointed out, the posterior extremities appear as the merest vestiges ; the animal being provided with a powerful swimming tail. Here the degrees of suppression in one direction (posterior extremities), and expansion in another direction (flippers and tail), are extreme. In the porpoise the suppression of the posterior extremities is complete—not even a vestige of them appearing.

The anterior extremities in birds and bats are enormously expanded to form wings ; the wings of birds being furnished with feathers, those of the bat with continuous thin membranes. These modifications are necessary to enable birds and bats to propel and sustain themselves in the air.

The flying fish is provided with greatly enlarged pectoral fins, the flying lizard, flying squirrel, and flying cat having expanded membranes extending between their anterior and posterior extremities which enable them to take great leaps in the air parachute-fashion.

The travelling extremities of animals which spend most or part of their time in water are, as a rule, webbed, as in the otter, platypus, and frog : in some cases they are expanded and webbed, as in the turtle, and in others they are, in addition, provided with a swimming tail, as in the tadpole, newt, and crocodile.

The rule is, that the travelling surfaces become expanded as the medium to be traversed becomes more tenuous and affords less support. A striking example of this is seen in the penguin, which swims and dives with wonderful alacrity, but cannot fly. In this case, the wings are very small, and are furnished with short stubbly feathers which are of no use in aërial flight. The same is true of running birds, such as the ostrich, emu, apteryx, dodo, &c. In these the wings have all but disappeared, and have no practical value as organs of flight.

The size and shape of the travelling extremities and organs are, in every instance, accurately adapted to the medium to be traversed. They form means to ends, and afford striking proofs of design.

In the case of animals whose movements are confined to the land the travelling extremities are invariably small. Examples are furnished by the dog, ox, and horse. The dog is provided with small feet each with five digits : the ox has feet with two digits, and in the horse the digits are reduced to one. The horse, is, however, among the fleetest of animals. The dwarfing of parts, in his case, is a manifest advantage. In the ostrich, the swiftest of living land birds, the digits are reduced to two. The extremities of the horse and ostrich are specially modified by the suppression of parts, and are the best adapted for speed : they afford the necessary support to the body and reduce the friction of the feet with the ground to a minimum. The feet of the horse and ostrich are more perfect travelling organs than the feet of quadrupeds and birds generally. They are not deteriorated organs when the function to be performed is taken into account. It is beside the question to say that useless rudiments or vestiges are to be found in the limbs of the horse. All that can be averred is that the extremities of the horse are framed on the same general plan or type as the limbs of other quadrupeds : the suppression of certain parts in this particular instance being a proof not of deterioration but of advance from a functional point of view. The suppression, as a matter of fact, supplies a striking example of design, as do the expanded webbed swimming extremities of seals, and the expanded flying extremities of birds and bats. The dwarfing or dropping of parts, and the enlarging or adding of other parts, strengthen rather than destroy the teleological argument. In all this we have manifestations of the highest possible wisdom. In order to live, animals must be provided with adequate, specially designed travelling organs, which enable them to move from place to place with celerity and precision. *These organs must be provided in advance*, that is, in the young and growing animals. It would prove an overwhelming disaster if animals had to wait for their travelling organs until they discovered that they would be useful to them. One of the great arguments for a Creator, Designer, and Upholder is the prevision everywhere apparent in the universe : everything, living and dead, is prepared against the time it is required. This preparation in advance is the very touchstone of design in the organic kingdom, and too little attention has hitherto been paid to it. Too little attention has also been paid to the travelling organs of animals in all existing forms of classification. As has been shown, the modes of life of animals are largely determined by them, and their importance should be recognised in some special manner.

What has been said of the organs of locomotion applies equally to the sense organs.

The fact that fishes which live in dark caverns have no eyes, or very rudimentary ones, is no argument against the special value of eyes to animals which live in the light. The eyes, perhaps, more than any other structures in the body, are necessary to the well-being of the higher animals. They are to be regarded as special creations. This follows, because they cannot be formed by externalities, or by efforts of volition on the part of the animals possessing them. It goes without saying that light does not form eyes, and that eyes cannot be developed at will because they are useful. The fact that rudimentary eyes are found in the lower animals is no proof that the more highly differentiated eyes of the higher animals are evolutions therefrom. The eye of the insect is, in some respects, a more highly developed, complex, and wonderful organ than the eye of a mammal. If, therefore, the travelling organs of animals are, in every instance, adapted to the work they have to perform, and the adaptations in some cases diminish and in others increase the number of parts employed, without destroying the types on which the organs are formed, we are forced to conclude that the modifications, be they great or small, are examples of design and means to ends. The vestiges in the limbs of the horse, when the ultimate object to be attained is kept in view, have as great value structurally and functionally as the added structures in the wings of birds and bats.

Parts may be dwarfed or suppressed and perform little or no function in one case, and added to and expanded in another case as required, without in any way impairing the argument for design. The atrophied, sightless eyes of fishes inhabiting dark caverns do not prove that the eyes of fishes living in well-lighted waters perform no useful function, or are not specially created. Vestiges or rudiments, wherever they occur, whether in young or adult organisms, only indicate type. They have no significance as evidence of failure of plan, or the miscarriage of design; neither do they prove that animals with vestiges are lineal descendants of animals with similar structures more highly developed. Conversely, the expanded wings of birds and bats do not prove that birds and bats are descended from fishes with large pectoral fins, of which the flying fish is the best example. The rudimentary hind legs of whales, pythons, and certain fishes do not prove that these animals are descended from bipeds. The so-called vestiges do not, strictly speaking, support the theory of descent; least of all do they weaken or destroy the teleological argument. That argument is based upon design and the adaptation of means to ends either in the young or adult condition. The embryonic whale is provided with teeth which it never uses, but it is also provided with a series of whalebone plates which take the place of teeth and are better adapted to deal with the soft nutritious food of the animal. Nature suppresses the teeth and develops the more useful whalebone plates intentionally. The teeth of the young whale indicate the mammalian type, but the modified whalebones (specially provided) supersede them as organs of mastication. The teeth of young mammals are arranged for in the general mammalian plan, but only come into being when required, and in anticipation of the food to be chewed. The teeth are variously arranged, classified, and modified according to the food to be consumed. In the herbivora the incisor and grinding teeth are largely developed; in the carnivora the canine teeth, and in the omnivora a golden mean is observed. The teeth afford unmistakable examples of design. The slow-worm (Anguis) and certain lizards possess no fore-legs, although they have in their bodies the shoulder girdles for attaching anterior limbs. These lizards do not suggest descent from higher animals with well-developed fore-legs. If the lizards referred to are deteriorated productions they provide examples of animals which are opposed to evolution; evolution being based upon progress from lower to higher forms. The vestiges or rudimentary structures are not confined to the hard parts of animals. They occur also in the muscles. Thus in man there are certain small muscles connected with each ear which, though seldom employed, can by practice be made to move the ears. These muscles are in constant requisition in quick-hearing animals, which prick or cock their ears and turn them in the direction of sounding bodies to catch the sound waves proceeding from them. The position, shape, and structure of human ears render these ear muscles of little value, but they are nevertheless typical, and important from the comparative anatomy point of view. Other human vestiges are the vermiform appendix of the alimentary canal, and the *plica semilunaris* or rudimentary nictitating membrane situated at the inner corner of each eye. In these cases the type is preserved; the function, because of structural modification and requirement, being more or less in abeyance. In some monkeys—the lemur, for example—the appendix vermiformis is a large blind end or cul-de-sac of the bowel: in birds and in reptiles the nictitating membrane or third eyelid is fully developed, and some think the primitive fishes of the Silurian period also possessed it. Several sharks of the present day display the nictitating membrane in perfection. One would be slow to connect the descent of man with the fish, the reptile, and the bird because he owns an imperfect nictitating membrane, or with the lemur because he possesses a modified appendix vermiformis.

The partial or complete suppression of an organ, or part of an organ, does not prove descent, neither does it imply any breakdown in design or the absence of an intelligent First Cause. On the contrary, it frequently means additional modification and additional care and forethought on the part of the Creator. If a part or a portion of a part can be spared in a particular instance, it is clearly the highest wisdom to dispense with it. Nature is careful of her resources both as regards matter and force. While she is generous and bountiful to an unparalleled extent, she is, nevertheless, no spendthrift.

The so-called vestiges, remnants, or rudiments also occur in plants, but into these it is not necessary to enter; suffice it to say, that their importance in determining descent has been greatly over-estimated and strained to bolster up and support what is essentially a weak case.

Professor Haeckel (as Mr. Darwin had done before him) endeavours to establish the doctrine of "natural selection" by the food supply and environment, by modifications and adaptations induced thereby, and by inheritance or descent. Like Mr. Darwin, he institutes a comparison between artificial and natural selection, and curiously enough falls into the same errors. He states that for the artificial breeding of plants and animals the most careful and continued selection on the part of an intelligent agent outside the plants and animals is required, but that for natural breeding no such intelligent agent or selector is necessary, and that physical forces and chance take the place of intellectual forces and design. His words are to the effect that: The struggle for life in natural selection acts with as much selective power as does the will of man in artificial selection. The latter, however, acts according

to a plan and consciously, the former without a plan and unconsciously. This important difference between artificial and natural selection deserves especial consideration. For we learn by it to understand how *arrangements serving a purpose can be produced by mechanical causes acting without an object, as well as by causes acting for an object.* The products of natural selection are arranged even more for a purpose than the artificial products of man, and yet they owe their existence not to a creative power acting for a definite purpose, but to a mechanical relation acting unconsciously and without a plan. Nothing could possibly be more illusory than the views here stated. They amount briefly to this, that desired results and means to ends can be as certainly obtained by accidental mechanical causes minus a plan as with a Creator plus a plan.

It is inconceivable that mere accidental mechanical arrangements can exercise such an overwhelming influence on plants and animals as is here claimed. In the case of man it is known that he has not changed physically for 9000 or 10,000 years. Could it for a moment be thought that the most complex of living organisms could be kept at a high efficient level for such a long period by mere accidental mechanical causes and as apart from a Creator, Designer, and Sustainer ?

Professor Haeckel sets out by asserting that every living thing is due directly or indirectly to spontaneous generation and externalities (*vide* footnote to p. 699).

According to him, "Every organism, every living individual, owes its existence either to an act of unparental or *Spontaneous* Generation (*Generatio Spontanea, Archigonia*), or to an act of parental generation or Propagation (*Generatio Parentalis, Tocogonia*)." [1]

His views on this subject are discussed further on.

He does not attempt to account for life or the directive forces which life represents. He avers that the seeds of plants and the eggs of animals are very greatly in excess of the food supply if they were all propagated—that there is a keen struggle for existence—that the stronger plants and animals only survive and perpetuate themselves, and that the stronger plants and animals owe their advantages to chance properties and qualities begotten of environment and physio-chemical processes. In all this there is no intelligence or design, everything is brought about mechanically. Plants and animals, according to him, are the product of dead matter and physical force, and have no directive power in themselves—they are brought into existence by externalities and kept going by externalities, apart from a Creator, intelligence, and design.

As I have explained elsewhere, mere environment and food cannot alter the constitution of plants and animals, and plants and animals have no inherent powers by which they can bring into prominence, develop, and perpetuate their good properties, while they suppress and weed out their bad properties. To do this an intellectual selector outside of themselves and a process of "in and in breeding" are required. The phrase "survival of the fittest" does not involve or convey the idea of natural selection, unless indeed it can be shown that the survivors owe their existence and pre-eminent position to the act of a selector, or to a selective power in the survivors themselves. But plants and animals, as explained, have no power to develop or suppress, at will, either their good or bad properties, and an extraneous selector, which is Nature herself or the Creator, is denied by Haeckel. The phrase "survival of the fittest" as now generally employed by evolutionists is a mere platitude. Haeckel, as stated above, holds that the seeds of plants and the eggs of animals are very greatly in excess of the food supply if they were all propagated, that there is a keen struggle for existence, and that only the stronger plants and animals survive. I would here remark that the struggle for life referred to is not so much between plants and animals of the same species, as between them and outside species ; the outsiders devouring the largest and strongest, equally with the smallest and weakest. The primary object of the great fecundity of plants and animals, especially the latter, is the supply of food, and the best of the offspring is preferably selected by the adult devourer, which is always more than a match for the immature and inexperienced young. The superabundant supply of seeds and eggs and young plants and animals is obvious, and has nothing to do with survival of the fittest in the sense in which it is usually employed. The prodigious food supply provided by the Creator for His creatures is well seen in fishes. The roe of the herring it is estimated contains 35,000 eggs, that of the mackerel 500,000 eggs, that of the sole 1,000,000 eggs, and that of the cod 3,000,000 eggs. Only part is of course propagated, but the number of young individuals successfully hatched out is truly enormous.

The kernel of the matter is as to how the fittest is produced. Blind chance, environment, and food cannot of themselves produce the fittest. This requires an intelligent selector, and that selector in nature is the Creator and the Creator alone. The fittest when produced repeats or reproduces itself. Here again there are the most convincing proofs of the operation of a First Cause and design. Each plant and animal only reproduces itself : an acorn does not produce a myrtle, nor an elephant a mouse. The persistency and permanency of plants and animals cannot be explained by accidental variation, however long continued : plants and animals in a state of nature

[1] "The History of Creation," 4th edition, vol. i., p. 187. London, 1899.

revert to their originals. The existence and persistence of plants and animals in time and space demand something more than spontaneous generation and the accidental vivifying of inanimate insentient matter: living things have to be housed, fed, and superintended, and special arrangements have to be made in advance for everything connected with their reproduction. Variation and adaptation are not synonymous and co-extensive terms. Variation may be the opposite of adaptation. It may not be improvement and advance, but deterioration and retrogression.

Professor Haeckel has explained his views on these points briefly as under: "The Theory of Selection, or Darwinism in its proper sense, to the consideration of which we now turn our attention, rests essentially upon the comparison of those means which man employs in the breeding of domestic animals and the cultivation of garden plants, with those processes which in free nature, outside the cultivated state, lead to the coming into existence of new species and new genera. . . . The differences of the individuals that come into consideration in artificial selection are very slight. . . . The causes through which, in artificial breeding, great effects are produced, are unusually simple, and these great effects are obtained simply by accumulating the differences which in themselves are very insignificant, and become surprisingly increased by a continually repeated selection. . . . We can trace all the different qualities which here come into play to physiological fundamental qualities of the organism, which are common to all animals and plants, and are most closely connected with the functions of *propagation* and *nutrition*. These two fundamental qualities are *transmissibility*, or the capability of *transmitting by inheritance*, and *mutability*, or the capability of *adaptation*. The breeder starts from the fact that all the individuals of one and the same species are different, even though in a very slight degree, a fact which is as true of organisms in a wild as in a cultivated state. . . . This fact of *individual difference* is the extremely important foundation on which the whole of man's power of breeding rests. . . . We are able to trace the mutability of individuals to the mechanical conditions of *nutrition*. . . . Now, just as we see that the mutability or adaptability has a causal connection with the general relations of nutrition in animals and plants, so too we find the second fundamental phenomenon of life, with which we are here concerned, namely, the capability of *transmitting by inheritance*, to have a direct connection with the phenomenon of *propagation*. . . . An organism may transmit to its descendants not only those qualities of form, colour, and size which it has inherited from its parents, but it may also transmit variations of these qualities, which it has acquired during its own life through the influence of outward circumstances, such as climate, nourishment, training, &c. . . . Now, if we examine the real nature of those two important properties of life, we find that we can trace them, like all physiological functions, to physical and chemical causes, to the properties and the phenomena of motion of those material particles of which the bodies of animals and plants consist. . . . These molecular phenomena of motion in the protoplasm, which call forth the phenomena of life, and are their active and true cause, differ more or less in all living individuals; they are of infinite variety.

"*Adaptation*, or deviation, is, on the other hand, essentially the consequence of material influences, which the substance of the organism experiences from the material surrounding it—from the *conditions of life* in the widest sense of the word. . . . The phenomenon of adaptation, or deviation, depends therefore upon the material influence which the organism experiences from its surroundings, or its conditions of existence; while the transmission by inheritance is due to the partial identity of the producing and produced organism. . . . Darwin's theory of the struggle for life is, to a certain extent, a general application of Malthus's theory of population to the whole of organic nature. It starts from the consideration that the number of *possible* organic individuals which might arise from the germs produced is far greater than the number of *actual* individuals which, in fact, do simultaneously live on the earth's surface. . . . Every organism, from the commencement of its existence, struggles with a number of hostile influences: it struggles against animals which feed on it, and to which it is the natural food, against animals of prey, and parasites; it struggles against inorganic influences of the most varied kinds, against temperature, weather, and other circumstances; but it also struggles (and this is much the most important!), above all, against organisms most like and akin to itself. Every individual, of every animal and vegetable species, is engaged in the fiercest competition with every other individual of the same species which lives in the same place with it. . . . And in the same manner we find that, among all animal species, all the individuals of one and the same species compete with one another to obtain these indispensable conditions of existence in the wide sense of the word. They are equally indispensable to all, but really fall to the lot of only a few—'Many are called but few are chosen.' . . . The position of the different individuals in this struggle for life is evidently very unequal. . . . We evidently have an infinite combination of influences, which, together with the original inequality of the individuals during the competition for the conditions of existence, favour some individuals and prejudice others. The favoured individuals will gain the victory over the others, and while the latter perish more or less early, without leaving any descendants, the former alone will be able to survive and finally to propagate the species. . . . But now (and this is a very important law of inheritance) if such a transmission of a favourable character is continued through a series of generations, it is not simply transmitted in the original manner, but it is constantly increased

and strengthened, and in a later generation it attains a strength which distinguishes this generation very essentially from the original parent. . . . The struggle for life acts as a means of selecting and transforming. The struggle of the different individuals to obtain the necessary conditions of existence, or, taking it in its widest sense, the inter-relations of organisms to the whole of their surroundings, produce mutations of form such as are produced in the cultivated state by the action of man's selection. . . . In artificial selection the will of man makes the selection according to a *plan*, whereas in natural selection, the struggle for life (that universal inter-relation of organisms) acts *without a plan*, but otherwise produces quite the same result, namely, a selection of a particular kind of individuals for propagation. . . . If, as we maintain, natural selection is the great active cause which has produced the whole wonderful variety of organic life on the earth, all the interesting phenomena of *human life* must likewise be explicable from the same cause. For man is, after all, only a most highly-developed vertebrate animal, and all aspects of human life have their parallels, or, more correctly, their lower stages of development, in the animal kingdom. . . . This distinctly and irrefragably shows that the soul of man, just as the soul of animals, is a purely mechanical activity, the sum of the molecular phenomena of motion in the particles of the brain, and that it is transmitted by inheritance, together with its substratum, just as every other quality of the body is materially transmitted by propagation. . . . The organ which, above all others, in man becomes more perfect by the ennobling influence of natural selection is the *brain*. The man with the most perfect understanding, not the man with the best revolver, will in the long run be victorious; he will transmit to his descendants the qualities of the brain which assisted him in the victory." [1]

From the foregoing summary of natural selection as interpreted by Professor Haeckel it will be evident that analogies and supposed facts are considerably strained to produce certain effects which by no means lie on the surface. No proof, however, of spontaneous generation is given, nor has it been shown that plants and animals depart (by variation) indefinitely from their originals. Such an assumption is negatived by the persistence and permanence of plants as we know them. It has not been established that practically new plants and animals can be manufactured by environment, externalities, and general conditions of life: it has not been demonstrated that physical molecular movements produce or maintain life—that reproduction is a merely mechanical process—that adaptations are born of environment, nutrition, and heredity—that there is an alarming scarcity in the food supply—that all living nature is engaged in a horrible internecine strife, and that there is no such thing as benignity in the world. The picture drawn by Haeckel, while striking in a way, is neither satisfactory nor pleasant. There is nothing, so far as facts are concerned, to show that living things are at eternal war with each other, and that they are habitually starved. The excess of germs, seeds, eggs, and young immature plants and animals is satisfactorily accounted for by the fact that these furnish, and designedly furnish, quite a large proportion of the food supply. The scheme of life (and of death, for the one is involved in the other) is on the whole a generous, indulgent, and beneficent scheme. It is less a case of armed neutrality and preying upon each other than one of trusted benevolence and good will. The merely mechanical view of existence fails to satisfy either the head or the heart. Still less does it satisfy the aspirations of the future either as regards the present world or the world to come.

Professor Haeckel's views on reproduction bear the impress of his mechanical theory of the universe. As has been shown, he attributes the origin of life to spontaneous generation, and having obtained, as he thinks, a rudimentary living form, he attributes to it the power to develop in various ways apart from a First Cause and design. He extends his mechanical theory to living matter, and makes no distinction between dead and living substances. There is, however, a profound gulf between the two. Dead matter does not break up and divide and repeat itself as living matter does. Living matter (and this is one of its distinguishing features) at certain determinate periods resolves itself into separate portions; the periods being known as reproductive periods, and the portions having the power of repeating themselves, each after its kind, *ad infinitum*.

The spontaneous generation theory does not explain the origin of life, neither does it explain reproduction in its various phases. These require a First Cause and design. The several processes which produce and transmit life are confined within certain limits and are predetermined. Given life and the power of reproduction, Professor Haeckel's classification of the several modes of propagation becomes interesting and intelligible. He puts it briefly thus: "Every organism, every living individual, owes its existence either to an act of unparental or Spontaneous Generation (*Generatio Spontanea, Archigonia*), *or to an act of Parental Generation or Propagation* (*Generatio Parentalis, Tocogonia*)." The non-sexual or monogonic propagation consists of self-division, formation of buds, or the formation of germ-cells or spores. The monera afford good examples of non-sexual reproduction. These low forms are about the size of a pin's head, and "consist of absolutely nothing but shapeless plasma or protoplasm, that is, of the same albuminous combination of carbon which, in infinite modifications, is found in all organisms, as the essential and

[1] "The History of Creation, or the Development of the Earth and its Inhabitants by the Action of Natural Causes," by Ernst Haeckel, vol. i., pp. 154–179. London, 1899.

never-failing seat of the phenomena of life. In a state of rest most monera appear as small globules of mucus or slime, invisible, or nearly so, to the naked eye. The monera reproduce themselves by simple self-division. This form of reproduction is fundamental, and extends to cells and the tissues and organs of animals, and the animals themselves. Every organism composed of many cells was originally a single cell, and becomes many-celled owing to the fact that the original cell propagated itself by self-division, and that the new individual cells in this manner remain together, and by division of labour form a community or a state.

"Propagation by the formation of buds is seen in plant-like animals, especially the corals, zoophytes, and hydroid polyps. It is universal in the vegetable kingdom. A third method of non-sexual propagation is by the formation of germ-buds, a fourth by the formation of germ-cells or spores. The latter leads to a form of propagation very difficult to explain, namely, sexual propagation.

"Sexual propagation prevails in the higher animals and plants. In all the chief forms of non-sexual propagation mentioned above—in fission, in the formation of buds, germ-buds, and germ-cells—the separated cell or group of cells was able by itself to develop into a new individual, but in the case of sexual propagation the cell must first be fructified by another generative substance. Two different cells, the male seed-cell (sperma) and the female egg-cell, must commingle; and out of this newly produced cell (Cytula) arises the many-celled organism. These two different generative substances, the male sperm and the female egg, are either produced by one and the same individual hermaphrodite (Hermaphroditismus), or by two different individuals (sexual separation, Gonochorismus).

"The simpler and earlier form of sexual propagation is through double-sexed individuals (Hermaphroditismus). It occurs in the great majority of plants, but only in a minority of animals, for example, in the garden snails, leeches, earth-worms, and many other worms. Every single individual among hermaphrodites produces within itself materials of both sexes—eggs and sperm. In most of the higher plants every blossom contains both the male organ (stamens and anther) and the female organs (style and germ). Every garden snail produces in one part of its sexual gland, eggs, and in another part sperm. Many hermaphrodites can fructify themselves; in others, however, copulation and reciprocal fructification of both hermaphrodites is necessary for causing the development of the eggs. . . . Sexual separation (Gonochorismus) is at present the universal method of propagation of the higher animals, and occurs, on the other hand, only in the minority of plants (for example, in many aquatic plants, such as, Hydrocharis, Vallisneria; and in trees, such as willows, poplars). Every organic individual, as a non-hermaphrodite (Gonochoristus), produces within itself only one of two generative substances, either the male or the female. The female individuals, both in animals and plants, produce eggs or egg-cells. The eggs of plants in the case of flowering plants (Phanerogama) are commonly called 'embryo sacs'; in the case of flowerless plants (Cryptogama), 'fruit spores.' In animals, the male individual secretes the fructifying sperm (sperma); in plants, the corpuscles, which correspond to the sperm. In the Phanerogama, these are the pollen-grains, or flower-dust; in the Cryptogama, a sperm, which, like that of most animals, consists of floating vibratile cells actively moving in a fluid—the zoosperms, spermatozoa, or sperm-cells.

"The so-called *virginal reproduction* (Parthenogenesis) offers an interesting form of transition from sexual reproduction to the non-sexual formation of germ-cells (which most resembles it); it has been demonstrated to occur in many cases among insects, especially by Siebold's excellent investigations. In this case germ-cells, which otherwise appear and are formed exactly like egg-cells, become capable of developing themselves into new individuals without requiring the fructifying seed. The most remarkable and most instructive of the different parthenogenetic phenomena are furnished by those cases in which the same germ-cells, according as they are fructified or not, produce different kinds of individuals. Among our common honey bees, a male individual (a drone) arises out of the eggs of the queen, if the egg has not been fructified; a female (a queen, or working bee), if the egg has been fructified. It is evident from this, that in reality there exists a wide chasm between sexual and non-sexual reproduction, but that both modes of reproduction are directly connected. The parthenogenesis of insects must probably be regarded as a *relapse* from the sexual mode of propagation (possessed by the original parents of the insects) to the earlier condition of non-sexual propagation. . . . The commingling of two homogeneous cells, which in the case of numerous Protista leads to non-sexual propagation by self-division or the formation of spores (sometimes as temporary conjugation, sometimes as permanent copulation), is the first step towards Amphigony. The second step is the heterogeneous development or divergence of the two cells, their division of labour and of form. The smaller and more agile cell becomes the male sperm-cell, the larger and less agile cell the female egg-cell. Both of them, on commingling, transmit their own peculiarities to the common product." [1]

Professor Haeckel attaches great importance to what he designates the two great organic constructive forces of *Inheritance* and *Adaptation*, and these he seeks to explain mechanically as apart from a First Cause and design.

[1] "The History of Creation," by Professor Ernst Haeckel, pp. 193 to 203 inclusive.

As already stated, he traces the origin of plants and animals to what he calls spontaneous generation, but the question has to be put, can plants and animals formed by so-called spontaneous generation, which, if it exists, is at best a casual, haphazard, accidental product, be credited with the potency, permanency, and far-reaching directive powers claimed for inheritance? A negative reply, it appears to me, must be given. Similarly, can adaptation, which means purposive modification to given ends, be claimed for plants and animals apart from pre-arrangement and design? I do not think it can. If spontaneous generation, which is regarded as a mechanical, accidental, purposeless assumption of life, be taken as the starting-point, it is illogical to infer that living things can reproduce themselves according to fixed laws (inheritance) and vary and modify themselves indefinitely to given ends (adaptation) at the bidding of externalities. It is quite otherwise if a Creator, Who makes dead and living matter and Who directs and controls both, be postulated. In this case, limits are set up between the inorganic and organic kingdoms; they are correlated and interact, but nothing is left to chance; laws are established for the proper conduct of the living and the dead; the dead does not take the initiative and lord it over the living; living things (under the guidance of a First Cause) act of themselves to given ends apart from irritability and the stimulation said to be produced by environment. One of two things is evident: either plants and animals must take the initiative and work out their own destinies under guidance; or accidental purposeless externalities (environment, food, climate, soil, temperature, &c.) must take the lead and make plants and animals what they are. The purely mechanical theory of the universe and of life is, for this and other reasons, in my opinion, wholly untenable. The organic constructive forces referred to by Professor Haeckel are only exhibited by living things, but if the living things cannot be accounted for apart from supposed spontaneous generation, which is haphazard in its nature and results, it is difficult to understand where the power of adapting comes in. In other words, if an apocryphal spontaneous generation has to be postulated to obtain the living thing, it follows that the so-called organic forces of inheritance and adaptation must also be postulated. It is a case of begging the question all round. Professor Haeckel says "that like other *vital* processes [mark the employment of the word *vital*] inheritance and adaptation proceed primarily from physical and chemical relations. They at times appear extremely complicated, but can nevertheless be traced back to simple, mechanical causes, to the attraction and repulsion of particles of matter, of molecules and of atoms."

Inheritance and the power of adaptation, it will be noted, are, according to Professor Haeckel, the offspring of the mere attraction and repulsion of particles of matter. Who or what, it may be asked, produces and guides the particles in the original formation of plants and animals? Who or what enables the particles to repeat and transmit themselves as plants and animals in a more or less unaltered form down the ages? Who or what controls the arrangement and re-arrangement of the particles to meet altered circumstances and bring about the definite results witnessed in the economy of plants and animals? The physical forces under divine guidance arrange the particles of matter to form crystals and other rudimentary structures; but they have no power to form living things, or to cause the living things to reproduce and repeat themselves, and, least of all, to cause living things to modify and adapt themselves to their surroundings. Professor Haeckel seems to be aware of the difficulties involved in his mechanical explanation of inheritance and adaptation, for he shifts his ground and employs the term *vital* in this connection. His words are: "We know them (inheritance and adaptation) to be genuine *physiological functions*, that is, *universal vital forces*."

His mechanical views are summarised as follows: "The life of every organic individual is nothing but a connected chain of very complicated material phenomena of motion. . . . The specific, definite tendency of this regular, continuous, and inherent *vital* [how *vital?*] motion depends, in every organism, upon the chemical mingling of the albuminous generative matter to which it owes its origin. . . . There can be no doubt as to the purely mechanical, material nature of this process. . . . In the sexual propagation of man and all higher organisms, inheritance, which is a purely mechanical process, is directly dependent upon the material continuity of the producing and produced organism. . . . The transmission of bodily and mental peculiarities is a purely material and mechanical process. . . . The most essential point is invariably a detachment from the parental organism of a portion possessing the faculty of leading an individual, independent existence. . . . But together with the material its *vital* [*sic*] properties—that is, the molecular motions of the plasma—are transmitted, and these then manifest themselves in its form."[1]

Professor Haeckel in other passages regards inheritance as the transmission of plastidule motion, and he credits the plastidules and molecules with souls. He also assumes that the plastidule movements (attraction and repulsion) are connected with sensations (pleasure and displeasure). He adds: "Without the assumption of some such lower (unconscious) form of sensation and will movement in matter the simplest chemical and physical processes remain unintelligible."[2]

From what is here stated it will be seen that Professor Haeckel ascribes to molecules and matter generally

[1] Professor Haeckel here confounds molecular motions with vital properties.
[2] Professor Ewald Hering has written (1870) a treatise, "On Memory as a Universal Function of Organic Matter."

the attributes usually ascribed to sentient, thinking, living matter. The indiscriminate use of language in this new sense is greatly to be regretted, as it mixes up things essentially distinct and different. Unfortunately the evil is not confined to zoology and physiology: it is also extending to physics. The latest innovation is to apply the theory of "natural selection" to the inorganic kingdom. It is clearly a mistake to confuse dead with living matter, and to apply the nomenclature peculiar to each as if they were fundamentally one and the same.

In discussing the subject of inheritance and descent as bearing on natural selection much emphasis is laid by Professor Haeckel upon the tendency to variation; the counteracting and correcting tendency to revert and breed back being conveniently left out of consideration. It is said, "The descendants of every organism are never absolutely equal in all points, but only similar in a greater or less degree. . . . All different individuals of every species, however like they may be in their first stages of life, become in the future course of their existence less like to one another. They deviate from one another in more or less important peculiarities, and this is a natural consequence of the different conditions under which the individuals live." This would lead one to infer an indefinite departure from types which is not sanctioned by the persistence and permanency of types in time and space. An excellent example of persistency is furnished by man himself.

It has to be observed in this connection that the variations which are here said to be caused by *varying external conditions* go on in the embryo where *the conditions remain the same*. Considerable confusion arises from the indiscriminate use by Professor Haeckel of the terms "variation" and "adaptation." These terms, as already explained, are not co-extensive and convertible. Variation in some cases is the opposite of adaptation. Adaptation implies improvement as regards existing circumstances: it also implies design and means to ends. Variation, on the contrary, is not unfrequently a mere temporary and useless departure from a standard which is persistent. Variation may even mean actual retrogression. Professor Haeckel thus expresses himself: "By adaptation or variation we understand the fact that the organism in consequence of influences of the surrounding outer world assumes certain new peculiarities in its vital activity, composition, and form which it has not inherited from its parents." He adds: "The physiological function of nutrition or change of substance affords a general explanation of adaptation or variation. By nutrition is here meant all the trophic changes which the organism undergoes in all its parts through the influence of the surrounding world—food, drink, air, sunlight, temperature, climate, soil, friendly and inimical influences, &c."

The subject of inheritance is by no means simple either from the theoretical or the practical point of view. It is the result of continuity, but it is, in certain cases, an intermittent or interrupted continuity. In the lower animals there are alternate generations, and in the higher ones bodily and mental peculiarities not unfrequently skip one or more generations and reappear at long and irregular intervals.

A much debated point in descent is the transmission of acquired characters. Every one admits that the parent or parents transmit to their offspring their own peculiar properties and qualities, physical, mental, and otherwise, but can they transmit improvements developed by and in themselves during any one generation? Authorities are pretty equally divided on the subject. Lamarck, Haeckel, and others believe they can. Professor Weismann holds a contrary opinion. He says: "We, as yet, do not know of any fact that would actually prove that acquired characteristics may be transmitted."

Another debated question in inheritance, adaptation, and descent is the effect produced by environment, habit, mode of life, &c.

Mr. Darwin and his followers attach much importance to externalities in making plants and animals what they are. Naegeli, however, maintains "that transformation proceeds from an internal, innate principle of perfecting; that this effects the transformation of the smaller or larger groups of forms, in a definite and progressive direction, and that selection exercises only a very trifling influence, or none at all." I wholly agree with Naegeli in what is here stated. I have never been able to understand why the order of nature should be reversed, and why living things, which are superior to dead things, should be at the mercy of the latter. It is in every way more natural to believe that living plants and animals, specially fashioned and guided, work out their own destinies, than that they are goaded into activity by the dead matter around them. Dead matter, strictly speaking, has no initiative; living matter, on the other hand, is aggressive and constantly on the move; it is born, grows, reaches maturity, propagates itself, declines and dies; care being taken that life is transmitted intact to succeeding generations.

Attempts have of late years been made to explain nearly all the facts in anatomy and physiology by natural selection, but the arguments employed are, in the majority of cases, more specious than convincing. Thus the distribution and arrangement of molecules and cells; the structure of the several tissues and organs; the peculiarities of sex; the characteristics of form; the several kinds of growth; embryonic and adult development and numerous other things, are all said to be dominated by it. Even the subject of mimicry is traced to it. The

latter affords a good example of special pleading. We are told that animals by "sympathetic selection" assume the colours of their surroundings; that plant lice and many other insects living on leaves are green; that insects which flutter round bright flowers are gay coloured; that the animals of the desert, the jerboa, gazelles, lions, &c., are browny yellow like the sand; that polar animals which live amongst ice and snow are white or grey; that many of these animals in summer become brownish-grey or blackish, as happens in the mountain hare, the ptarmigan, and so on. Mr. Darwin argues that such colours as agree with the colour of the habitation are of the greatest use to the animals concerned. "If (it is stated) these animals are animals of prey, they will be able to approach the object of their pursuit more safely and with less likelihood of observation, and, in like manner, those animals which are pursued will be able to escape more easily, if their colour is as little different as possible from that of their surroundings. If, therefore, originally an animal species varied so as to present cases of all colours, those individuals whose colour most resembled the surroundings must have been most favoured in the struggle for life. They remained more unobserved, maintained and propagated themselves, while those individuals or varieties differently coloured died out."

What advantage, it may be asked, can possibly be derived by animals from being coloured like their surroundings when the preying animals and the animals preyed upon are each coloured alike? A white mouse would have no protection from a white weasel, nor a white ptarmigan from a white owl or other white bird of prey. If the mouse and ptarmigan because of their colour evaded detection, so the stealthy approach of the weasel and the owl would be concealed to their detriment and possible destruction. The argument cuts both ways. The subject of mimicry cannot be explained by so-called natural selection.

It is quite true that animals, in many cases, resemble their surroundings both in colour and form. We have examples of this in leaf and stick insects. It is, however, also true that animals, in certain cases, form the most striking contrasts in colour and outline to their surroundings, and yet escape detection by forming part of a harmonious whole. The explanation in such cases is that there are schemes of colour as well as of form in nature, and both indicate design. Colour, sympathetic or otherwise, is not an exclusive attribute of animals, for colours of every conceivable hue are found in inanimate nature—in the clouds, in fluids, in minerals, &c. Here there can be no trace of natural selection. The sky, especially at sunrise and sunset, is flooded with the most gorgeous display of colours, of every possible tint, all inextricably blended according to a colour scheme. The rainbow affords a glorious example. In the inorganic kingdom, hidden from every eye, the same thing happens. Deposits of sand, clay, rocks, crystals, metals, and inanimate things generally, have their schemes of colour, and the delicacy and intensity of their hues in many cases rival those of the wings of butterflies and the feathers of birds. Similarly, shells, which are dead things, display the most extraordinary harmonies in colour—the tints ranging through the whole gamut of colour. In plants we have examples of all the colours of the rainbow, and these are so blended as never to jar. On the sea-bottom plants and animals are mixed up with the sand, pebbles, rocks, &c., to form a harmonious colour scheme; the living and dead things combining to produce a common result. The same thing happens in the landscape, where the plants and animals mingle with the sand, the soil, the rocks, &c., to form the familiar colour scheme which we all so greatly admire and appreciate. The so-called sympathetic colouring can consistently be referred to a colour scheme in which natural selection finds no place. Nor does the matter rest here. The tissues of plants and animals during development and decay display the most delicate harmonies in colour. Professor Prince has lately directed attention to the transcending delicacy and beauty of the colours seen in fishes externally and internally. The dolphin when dying assumes a great variety of beautiful tints which can avail nothing and are of no possible use; and many animals during nervous excitement induce evanescent changes of colour. The frog, under such circumstances, can vary the size and position of its pigment spots; the chameleon can temporarily change its complexion, and man may become pale or flushed under emotion. The change of colour in these and other cases is in no way connected with natural selection.

Similar remarks have to be made in connection with so-called "sexual selection." It is claimed that the peculiarities of sex, especially those of the male sex, are due to selection. Thus, the mane of the lion, the antlers of the stag, the spurs, wattles, and gayer plumage of the cock, &c., are said not to be inherent but acquired structures. Now if there is one thing more than another that is fundamental and deep rooted in higher living things it is that of sex. The males, with few exceptions, are the finer and stronger.[1] They are so in virtue of inherent original powers from the outset. Even in the embryo the male is distinguished by its greater size. This is designedly so. The function of the male is to protect as well as propagate. He is bigger, handsomer, fiercer, and more resourceful. He displays many of the peculiar male attributes before he reaches maturity, and before the question of reproduction can even be considered. If, however, males are endowed with certain of their virile attri-

[1] In the case of birds of prey, where the females perform a large share of the killing and carrying of food for the voracious young, the female bird is generally the larger and fiercer.

butes *in utero* and before they attain the adult, reproductive stage, it follows that "sexual selection" cannot be credited with peculiarities which make their appearance before such selection can possibly come into operation. There are admittedly great differences between the males and females in the higher animals—the males lead, the females follow. Greater strength, courage, and endurance are required in the former, but the physical properties and intellectual qualities of the males are duly arranged for in the nature of things: they are not left to chance or the whim of the individuals themselves. The organs of offence and defence and the psychical qualities which characterise males are vouchsafed to them for the most part before the virile, reproductive period is reached. The advent of the male structures anticipates their function. This is an important point, to which I would strongly direct attention. Structures must, in every instance, precede function. Differentiation of labour demands this. To have function, even in its simplest form, there must be a special apparatus to produce it. The testes of males and the ovaries of females are produced at a very early period, and long before spermatozoids and ova are required for the purposes of reproduction. The function of reproduction is provided with its special organs and apparatus quite apart from sexual selection. The same is true of all other functions of the body. The heart is formed in advance to propel blood, the chest and lungs to propel air, the alimentary canal to receive, transmit, and digest food, the muscles to actuate the bones as levers, the glands to secrete and excrete, the brain and nervous system to direct and co-ordinate the structures which produce the functions.

It is a matter of primary importance to distinguish between structure and function, and to make sure that structure always precedes function. This is the more necessary, as numerous attempts have recently been made to reverse the order of nature, and to make function precede and produce structure. In these cases the wish is the father to the thought. The object is to transfer the production of organs from the Creator or First Cause to the creature, and to endow the latter with the power of producing its own organs mechanically and apart from design.

Professor Wilhelm Roux wrote in 1881 a work entitled "The Struggle of the Parts in Organisms: a Contribution towards the Completion of the Doctrine of the Mechanical Origin of what is Suitable." In the first part of his work he discusses the functional adaptation of the several organs, and the transmissibility of these effects, more especially *the functional self-formation of suitable structures*, and explains them as a necessary result of the increase or lessening of habits. In the second portion he investigates the struggle of the parts in the organism, and shows that the inequalities of the parts, the unequal relations of their activity and nutrition, and of the change of their substance and growth, must necessarily lead to a struggle among them for existence; and that this applies as much to the several organs, and to the tissues of which the organs are composed, as to the single cells of which the organs are composed, and finally even to the active molecules of which the plasma of the cells and their kernels are composed (plastidules or micellæ). Roux points out "that the increased activity of an organ strengthens its special functional capacity, whereas, on the contrary, a lessened activity will diminish it (in Lamarck's sense); and further, that *through the influence of functional stimulus* parts that appear designed for a definite purpose, and which have attained the highest conceivable perfection, *are produced and formed* in a directly mechanical way, without any other final cause, with a purpose, coming into play." I direct the attention of the reader to the following passage in the above quotation: "Through the influence of functional stimulus parts . . . are produced and formed in a directly mechanical way." This can only mean that function leads to the formation of new parts. In opposition to this I maintain that the part or parts must be formed before function of any kind can occur. Given the organ or organs, every variety of function is possible. The organ or organs must, however, in every case be formed before function asserts itself. The actual existence of the organs is a fundamental necessity. As plants and animals cannot produce their own organs in a haphazard or accidental way, and as they cannot be the products of mere externalities in any shape, it follows that the only explanation that can be given of them is that they are original endowments, and directly traceable to a First Cause and design.

The following contradictory passages from Professor Haeckel's "History of Creation" illustrate the point here raised. Speaking of bones, muscles, blood-vessels, nerves, glands, &c., he says: "The relations of their structure appear to be arrangements of the most perfect design for a given purpose that can be conceived; and yet they have been produced without any pre-ordained purpose, in fact, in a purely mechanical manner, by means of the peculiar activity of the organs themselves in connection with their functional stimulus. The different function naturally produces its reaction in changing the form, and the physiological division of labour necessarily determines the morphological differentiation, that is, the divergence of character." Here, it will be noted, Haeckel attributes the formation of the organs to mechanics, and to the peculiar activity of the organs themselves, apart from design. He recognises "the means to ends," but denies the design which means to ends imply. In the attempt to establish natural, sexual, and other selection, things which are wholly different are mixed up, and the order and sequence of nature reversed. It is safe to assert that structure, as already explained, in every instance precedes function. The invariable rule is: no structure no function. Similarly, plants and animals must be formed before they can take

any part in the great scheme of organic nature. Neither the organs nor the organisms can be produced by mere mechanical processes from inorganic matter apart from a Creator and design.

Mr. Darwin purposely avoided dealing with the subject of life. He observes that he has "nothing to do with the origin of the soul, nor with that of life itself," and adds: "I imagine that probably all organic beings which ever lived on this earth descended from some primitive form, which was first called into life by the Creator."

As regards so-called sexual selection it is not denied that the higher animals, man included, have their likes and dislikes, and that their likes and dislikes play a prominent part in mating. This is selection of a kind, but it falls very far short of producing the sexual organs or characteristics of either the male or the female. Given the sexual organs and characteristics of both sexes, likes and preferences and dislikes and aversions certainly manifest themselves when puberty is reached. The song-bird with the strongest and most melodious voice, and the most elegantly formed and most gaily plumaged bird, will, as a rule, captivate the females. Similarly, the great size, strength, courage, and splendid symmetry of the males of mammals secure for them the love and affection of the finest females. The same holds true of man himself, but in his case the merely physical properties are, in many cases, largely supplanted by brilliant mental qualities which count for much with educated, refined women. Nor is the selection by any means confined to the males. The females, although seldom aggressive, exercise their witcheries and blandishments in a quiet, unobtrusive way which, in many cases, make their lords their slaves. The selection here spoken of has equalising, levelling elements in it, and results in a high average standard: the short, the tall, the stout, the thin, the courageous, the timid, the dark, the fair, as a rule select their opposites. This is quite another thing from saying that the sexual organs and characteristics are produced by "sexual selection."

The sexual organs, as explained, are fundamental and characteristic, and are produced in both sexes long before the period of adolescence when they are called upon to discharge their peculiar functions.

SPONTANEOUS GENERATION as advocated by Professor Haeckel

Professor Haeckel, while a staunch believer in spontaneous generation, has not been able to adduce any reliable experiments or proofs in support of his favourite theory. His arguments are largely those of the apologist. He sets out by saying that in the early geologic period there was an excess of carbonic acid in the atmosphere—that carbon is a prime ingredient in all living things, and that while spontaneous generation may not be possible at the present day it may have been possible at the dawn of creation. He represents the world as consisting at first of a flaming molten mass which contracted and solidified on cooling; he assumes that it became covered with water as the result of condensing steam, and that ultimately it was divided into land and water and invested with an atmosphere differing considerably from our present atmosphere. The water and atmosphere were, in his opinion, the necessary harbingers of life, and he assigns life to crystals as well as to plants and animals. He founds his argument largely upon Emanuel Kant's famous gas theory of the universe, and altogether ignores a Creator and special acts of creation. He is, however, forced to admit that Kant's theory is not altogether satisfactory, and epitomises it as follows: "Kant's cosmogony maintains that *the whole universe, inconceivable ages ago, consisted of a gaseous chaos.* All the substances which are found at present separated on the earth, and other bodies of the universe, in different conditions of density—in the solid, semi-solid, liquid, and elastic fluid or gaseous states of aggregation—originally constituted together one single homogeneous mass, equally filling up the space of the universe, which, in consequence of an extremely high degree of temperature, was in an exceedingly thin gaseous or nebulous state. The millions of bodies in the universe which at present form the different solar systems did not then exist. They originated only in consequence of a universal rotatory movement, or rotation, during which a number of masses acquired greater density than the remaining gaseous mass, and then acted upon the latter as central points of attraction. Thus arose a separation of the chaotic primary nebula, or gaseous universe, into a number of rotating nebulous spheres, which became more and more condensed. Our solar system was such a gigantic gaseous or nebulous ball, all the particles of which revolved round a common central point, the solar nucleus. The nebulous ball itself, like all the rest, in consequence of its rotatory movement, assumed a spheroidal or a flattened globular form.

"While the centripetal force attracted the rotating particles nearer and nearer to the firm central point of the nebulous ball, and thus condensed the latter more and more, the centrifugal force, on the other hand, always tended to separate the peripheral particles further and further from it, and to hurl them off. On the equatorial sides of the ball, which was flattened at both poles, this centrifugal force was strongest, and as soon as, by increase of density, it attained predominance over the centripetal force, a circular nebulous ring separated itself from the rotating ball. This nebulous ring marked the course of future planets. The nebulous masses of the ring gradually condensed and became a planet, which revolved round its own axis, and at the same time rotated round the

central body. In precisely the same manner, from the equator of the planetary mass, as soon as the centrifugal force gained predominance over the centripetal force, new nebulous rings were ejected, which moved round the planets as the latter moved round the sun. These nebulous rings, too, became condensed into rotating balls. Thus arose the moons, only one of which moves round our earth, whilst four move round Jupiter, and six round Uranus. The ring of Saturn still shows us a moon in its early stage of development. As by increasing refrigeration these simple processes of condensation and expulsion repeated themselves over and over again, there arose the different solar systems, the planets rotating round their central suns, and the satellites or moons moving round their planets.

"The original gaseous condition of the rotating bodies of the universe gradually changed, by increasing refrigeration and condensation, into the fiery fluid or molten state of aggregation. By the process of condensation, a great quantity of heat was emitted, and the rotating suns, planets, and moons soon changed into glowing balls of fire, like gigantic drops of melted metal, which emitted light and heat. By loss of heat, the melted mass on the surface of the fiery fluid ball became further condensed, and thus arose a thin, firm crust, which enclosed a fiery fluid nucleus. In all essential respects our mother earth probably did not differ from the other bodies of the universe." According to Haeckel "*the cosmological gas theory* harmonises with all the general series of phenomena at present known to us, and stands in no irreconcilable contradiction to any one of them. It is purely mechanical or monistic, makes use exclusively of the inherent forces of eternal matter, and entirely excludes every supernatural process, every prearranged and conscious action of a personal Creator."

He adds the following passage, and it is a very important and significant one: "The notion of an original gaseous chaos filling the whole universe presents great difficulties of various kinds. A great and unsolved difficulty lies in the fact that the Cosmological Gas Theory furnishes no starting-point at all in explanation of the first impulse which caused the rotary motion in the gas-filled universe."

It will be noted that Kant fails to explain the origin of motion. Haeckel in like manner fails to explain the origin of life. In this connection he says: "It was not till the earth's crust had so far cooled that the water had condensed into a fluid form, it was not till the hitherto dry crust of the earth had for the first time become covered with liquid water, that the origin of the first organisms could take place. For all animals and all plants—in fact, all organisms—consist in great measure of fluid water, which combines in a peculiar manner with other substances, and brings them into a semi-fluid state of aggregation. We can, therefore, from these general outlines of the inorganic history of the earth's crust, deduce the important fact, that at a certain definite time life had its beginning on earth, and that terrestrial organisms did not exist from eternity."

Haeckel here associates the production of life with water, which he postulates. He associates it further on with carbon. He observes: "In all living bodies, without exception, there is a certain quantity of water combined in a peculiar way with solid matter, and owing to this characteristic combination of water with solid matter we have that soft state of aggregation, neither solid nor liquid, which is of great importance in the mechanical explanation of the phenomena of life. Its cause lies essentially in the physical and chemical properties of a simple, indivisible, elementary substance, namely, *carbon*.

"Of all elements, carbon is to us by far the most important and interesting, because this simple substance plays the largest part in all animal and vegetable bodies known to us. It is that element which, by its peculiar tendency to form complicated combinations with the other elements, produces the greatest variety of chemical compounds, and among them the forms and living substance of animal and vegetable bodies. . . . By the combination of carbon with three other elements, with oxygen, hydrogen, and nitrogen (to which generally sulphur, and frequently, also, phosphorus is added), there arise those exceedingly important compounds which we have become acquainted with as the first and most indispensable substratum of all vital phenomena, the albuminous combinations, or albuminous bodies (proteid matter). Of these, again, the most important are the plasson-body or plasma combinations (karyoplasm and protoplasm)."

Professor Haeckel begins with glowing, molten masses, of which the earth is one. The earth cools and solidifies on the surface; water (due to the condensation of steam) and the elements make their appearance. The most important elements for life are oxygen and nitrogen, which mainly form atmospheric air; oxygen and hydrogen, which form water; and oxygen, hydrogen, nitrogen, and carbon, which form protoplasm, regarded by many as the fundamental "life stuff." He assumes that the so-called elements (some seventy-five in number) "are only different forms of combination of two different primary elements—matter and ether; the matter atoms being endowed with attraction, the ether atoms with repulsion." He makes for simplicity in the production of the elements. He also makes for simplicity in the production of life. He remarks: "Of late years we have become acquainted with Monera, organisms which are, in fact, not composed of any organs at all, but consist entirely of shapeless, simple, homogeneous matter. The entire body of one of these Monera, during life, is nothing more than a shapeless, mobile little speck of mucus or slime, consisting of an albuminous combination of carbon. . . . These simplest

of organisms are of the utmost importance for the theory of the first origin of life. But most other organisms also, at a certain period of their existence—at least, in the first period of their life—in the shape of egg-cells or germ-cells, are essentially nothing but simple little lumps of such albuminous formative matter, known as cell-slime or protoplasma. . . . We are now able to trace the wonder of the phenomena of life to these substances, and we can demonstrate the *infinitely manifold and complicated physical and chemical properties of the albuminous bodies to be the real cause of organic or vital phenomena*. . . . Every animal and vegetable species has arisen only *once* in the course of time and only in *one* place on the earth—its so-called 'centre of creation'—by natural selection. I share this opinion of Darwin's unconditionally, in respect to the great majority of higher and perfect organisms, and in respect to most animals and plants in which the division of labour, or differentiation of the cells and organs of which they are composed, has attained a certain stage. . . . On the other hand, I consider it very probable that certain exceedingly imperfect organisms of the simplest structure, forms of species of an exceedingly indifferent nature, as, for example, many single-celled Protista (Algæ as well as Amœbæ and Infusoria), but especially the Monera, the simplest of them all, have several times or simultaneously arisen in their specific form in several parts of the earth."

Professor Haeckel attempts to give a detailed account of the origin of life. He says: "Only such homogeneous organisms as are yet not differentiated, and are similar to inorganic crystals in being homogeneously composed of one single substance, could arise by spontaneous generation, and could become the primeval parents of all other organisms. . . . We can conceive this to take place in a purely physical manner, by the condensation of the innermost central part of the albumen. The more solid, central mass, which at first gradually shaded off into the peripheral plasma, becomes sharply separated from it, and thus forms an independent, round, albuminous corpuscle, the kernel; and by this process the Moneron (simplest living form) becomes a cell. . . . Every animal and every plant, in the beginning of its individual life, is a simple cell. Man, as well as every other animal, is at first nothing but a simple egg-cell, a simple lump of mucus, containing a kernel.

"In the same way as the kernel of the organic cell arose in the interior or central mass of the originally homogeneous lump of plasma, by separation, so, too, the first *cell-membrane* was formed on its surface. This simple, but most important process, as has already been remarked, can likewise be explained in a purely physical manner, either as a chemical deposit, or as a physical condensation in the uppermost stratum of the mass, or as a secretion. . . . As soon as, by condensation of the homogeneous Moneron, a cell-kernel arose in the interior and a membrane arose on the surface, all the fundamental parts of the unit were furnished, out of which, by infinitely manifold repetition and combination, as attested by actual observation, the body of higher organisms is constructed. . . . Among these form-units we distinguish two main groups, namely, the cytods and the genuine cells. The *cytods* are, like the Monera, pieces of plasma without a kernel. *Cells*, on the other hand, are pieces of plasma containing a kernel or nucleus. Each of these two main groups of plastids is again divided into two subordinate groups, according as they possess or do not possess an external covering (skin, shell, or membrane). We may accordingly distinguish the following four grades or species of plastids, namely: 1. Simple cytods; 2. Encased cytods; 3. Simple cells; 4. Encased cells. The *simple cytods* (Gymnocytoda), naked particles of plasma without kernel, like the still living Monera, are the only plastids which directly come into existence by spontaneous generation. . . . All the other forms of plastids or form-units met with, besides these, have only subsequently arisen out of these four fundamental forms by natural selection, by descent with adaptation, by differentiation and transformation."

Now admitting all the above to be true, we are not apprised as to the real nature of life, and the manner, mode, and time of its production. Haeckel does not inform us how or why his moneron, or simplest living being, came into existence; how or why homogeneous organisms composed of one single substance condense in the centre to form a kernel or nucleus; how or why an originally homogeneous lump of plasma separates to form the first cell membrane, to become heterogeneous, and how the differentiations, transformations, and adaptations occur which convert a moneron into a man. He does not actually deal with the beginning and the essence of life. He leaves out the mainspring; it is the play of "Hamlet" with Hamlet absent. What set the atoms in motion to form the molecules of his moneron? What caused the molecules of his moneron to aggregate in the centre to form a kernel or nucleus? What marshalled the molecules of his cell on its surface to form a cell wall? What directed the growth of his cell or cells? What determined the division and increase of his cells to form tissues, organs, and organisms each after their kind? What insured the reproduction and descent of plants and animals down the ages? No mere physical or mechanical arrangement can furnish satisfactory answers to these questions. No one has yet discovered the origin of life. All that can be said is that it is no chimera, and, so far as can be made out at present, is a something added to matter by the great First Cause. As such, it must be accepted as matter itself is accepted. There is no getting behind it—no explaining it away. It certainly is not the result

of spontaneous generation. Like everything else in the world, it is conditioned. It is limited in its duration and extent. It is not given a free hand either in time or space. Mr. Darwin in his "Origin of Species by Means of Natural Selection," as I have already explained, takes life for granted, and Professor Haeckel, I am bound to admit, has not succeeded in showing that it is due to spontaneous generation. The latter bolsters up his arguments by asserting (what is quite true) that certain substances which were believed to exist only in living organisms have been produced artificially; that all the elements found in plants and animals are also found in the inorganic kingdom, and that crystals grow, after a fashion. This is, however, quite a different thing from saying that originally all inorganic and organic matter was fundamentally homogeneous and simple, and that crystals live after the manner of plants and animals. He is not entitled to assert that "all vital phenomena and formative processes of organisms are as directly dependent upon the chemical composition and the physical forces of organic matter as the vital phenomena of inorganic crystals—that is, the process of their growth and their specific formation, are the direct results of their chemical composition and of their physical condition." The term *vital* as applied in this passage to crystals is inaccurate and confusing, and even an abuse of language. There is no proof that inorganic and organic matter were homogeneous and simple at the outset, or at any period of their existence. The tendency of modern science, as already pointed out, is gradually to increase the number of elements existing in the universe, and there are good grounds for believing that the monads, or sub-atoms, atoms, molecules, and cells are never strictly homogeneous and identical.

Protoplasm composed of oxygen, hydrogen, nitrogen, carbon, plus sulphur and phosphorus, cannot be considered a simple substance, and the same is true of inorganic materials as a class. If the inorganic materials forming crystals and the organic materials forming plants and animals were absolutely identical and homogeneous in all their parts and particles at the outset, differentiation would be impossible, and the fundamental law of reproduction by which like produces like would be inoperative or non-existent. A certain difference and differentiating power must be claimed for all matter, living and dead. Absolutely identical homogeneous matter can achieve nothing, and must remain what it is, whether in the solid, liquid, or gaseous states; the mere aggregation or separation of its particles does not essentially alter its original character and constitution. Moreover, there is no need to assume the identity and homogeneity of inorganic and organic matter in the universe. The scheme of the inorganic and organic kingdoms is essentially one of action and re-action, and this is more effectively carried out with heterogeneous than homogeneous substances. Heterogeneity and differentiation cannot logically be deduced from homogeneity and absolute sameness. This remark applies to the simplest organisms, and to the beginnings of the most complex ones. The power to differentiate implies original difference in an actual or potential form. An oak is not produced from a beech nut, a fish from a fowl, or a bird from a mammal. Original differences can alone account for ultimate differences. The so-called differentiations and adaptations in plants and animals are the outcome of original differences. The power of adapting implies an adapting machinery. In Haeckel's references to life, the materials found in living things only are spoken of: the master mind and hand which weld them into living wholes and start them on their wonderful careers are entirely lost sight of. If Haeckel's views are accepted we get, at best, inanimate plant and animal machines devoid of movement. They cannot start themselves, neither can they keep themselves going, or repair themselves when they get out of order; least of all can they adapt themselves to varying circumstances, and work in given directions and to definite ends. To accomplish these results, a Creator, Designer, and Upholder is necessary.

There is absolutely no warrant for the following positive statements by Haeckel: "It now never occurs to a physiologist to consider any of the vital phenomena as the result of a mysterious *vital force*, of an active power working for a definite purpose, standing outside of matter and, so to speak, taking only the physico-chemical forces into its service. Modern physiology has arrived at the strictly monistic conviction that all the vital phenomena, and, above all, the two fundamental phenomena of nutrition and propagation, are purely physico-chemical processes, and directly dependent on the material nature of the organism, just as all the physical and chemical qualities of every crystal are determined solely by its material composition. . . . We must ultimately reduce all vital phenomena, and, above all, the two fundamental phenomena of nutrition and propagation, to the properties of the carbon. *The peculiar chemico-physical properties, and especially the semi-fluid state of aggregation, and the easy decomposability of the exceedingly composite albuminous combinations of carbon, are the mechanical causes of those peculiar phenomena of motion which distinguish organisms from anorgana, and which in a narrow sense are usually called life* (*crystals*). . . . There exist no complete differences between organic and inorganic natural bodies, neither in respect to form and structure, nor in respect to matter and force; the actually existing differences are dependent upon the peculiar nature of the *carbon:* there exists no insurmountable chasm between organic and inorganic nature. . . . From an apposition of particles arise the mathematically definite crystalline shapes. In like manner the growth of organisms takes place by the accession of new particles. The only difference is that

in the growth of organisms, in consequence of their semi-fluid state of aggregation, the newly added particles penetrate into the interior of the organism (intussusception), whereas anorgana (crystals) receive homogeneous matter from without only by apposition or an addition of new particles to the surface. This important difference of growth by intussusception and by apposition is obviously only the necessary and direct result of the different conditions of density or state of aggregation in organisms and anorgana."

Professor Haeckel thus sums up: "The origin of the first Monera by spontaneous generation appears to us as a simple and necessary event in the process of the development of the earth. We admit that this process, as long as it is not directly observed or repeated by experiment, remains a pure hypothesis. But I must again say that this hypothesis is indispensable for the consistent completion of the non-miraculous history of creation."

To the passage now quoted the obvious reply is, that living things were not necessarily a part of the outfit of the universe, and the history of creation can never appear other than miraculous even to the most stupendous and far-reaching intellects. It is too much to place a mere hypothesis which vaunts absence of intelligence and design, and relies on chance chemico-physical processes, in the balance against a First Cause working to given ends. The chemico-physical process and mechanical arrangements advocated by Haeckel are only part of the equipment of life: they do not constitute life. So far as is known at present no kind of matter, however circumstanced and modified, can assume life *de novo*. Life is an original endowment by the Creator, and is transmitted down the ages in an infinite variety of forms in plants and animals. It is an energising, directive agency which appropriates, controls, and shapes ordinary matter to given ends. It is the outcome of intelligence and design, and never works in a haphazard manner or blindly. In this sense, life is the crowning glory of the universe, and, as such, entitled to a first place in the estimation of the philosopher, the physicist, the physiologist, and the psychologist. To belittle life is to belittle all the achievements which make man what he certainly is—the coping-stone of the organic kingdom. Life is too precious a possession to be bandied about in a haphazard way as the sport of the elements, which is virtually what Haeckel endeavours to make it.

§ 216. Short History of Spontaneous Generation—Recent Views.

It may be useful in this connection to give a few facts regarding the history of spontaneous generation. The generation of life from inanimate matter in some accidental haphazard way has long been a favourite subject of study with certain biologists, chemists, and physicists. As a matter of fact, it dates back to the time of Aristotle. "He, as well as most of the naturalists who lived previous to the time of Harvey, were of opinion that dust, decomposed flesh, and other dead substances might, under the influence of heat, air, and water, give rise to vital organisms."

The subject of spontaneous generation is one of immense difficulty, and beset on all hands with possible fallacies. There are two hostile camps: the one maintains that life is a thing by itself, an entity, a something added to inanimate matter, and that plants and animals, when once created, reproduce themselves in endless succession by division, by budding, by spores, germs, seeds, eggs, &c. The other camp declares that, under certain circumstances, life manifests itself *de novo* in non-living, inorganic dead matter, quite apart from a Creator and existing plants and animals.

Those who believe in life as a separate entity, headed by the famous M. Pasteur, affirm that spontaneous generation is a myth, and that wherever life appears, however rudimentary it may be, it is, in every case, due to germs existing in the matter in which it occurs, or in the air investing and in contact with the matter. In support of their contention they say, that if the matter in question (solid, semi-solid, or fluid) be exposed to very high temperatures or sterilised in some way to destroy the germs, and if the air be excluded, no life will appear in the matter, however long it may be kept. They add, that if the air be re-admitted to the matter so sterilised, after a longer or shorter period, according to climate, time of year, temperature, moisture, &c., life will appear. They infer that the germs which are in the air fall upon the matter, and that they fructify on and in the matter: they, in fact, trace the life to the presence of living germs in the air.

M. Pasteur, Professor Tyndall, and Professor Lister (now Lord Lister), advocate and support the germ theory of the production of life: M. Pouchet, Professor Bennett, and Dr. Bastian the spontaneous generation theory.

M. Pasteur demonstrated by a series of very delicate and ingenious experiments the existence, in large numbers, of germs in the air. Lord Lister, in a paper communicated to the Royal Society of Edinburgh in 1873, showed that many of the forms believed to be the result of spontaneous generation were neither more nor less than the transitional or developmental forms of certain fungi which could be planted and raised from germs. He, in fact, by the aid of cultures, succeeded not only in planting the minute fungi in question, but, what is more important, he succeeded in tracing them through all their stages, from the germ to the bud, from the bud to the perfect plant, and from the perfect plant back again to the germ. The view that certain filamentous fungi may give origin to

toruloid and bacteric forms was new to science, and has done more towards establishing the truth of the germ theory and annihilating that of spontaneous generation than any experiments with which I am acquainted.

Lord Lister was good enough to demonstrate to me with great care, under the microscope, the several phases through which the fungi pass, and I had no doubt in my own mind as to the accuracy of his results and the outstanding importance of the conclusions at which he had arrived.

In 1876 the subject of spontaneous generation was most ably discussed by Professor Tyndall.[1] Professor Tyndall, of all our British philosophers, believed in matter and the extraordinary powers possessed by matter: nevertheless, after a careful and candid consideration of the whole subject extending over many years, he declared the theory of spontaneous generation to be utterly false. Professor Tyndall adopted a most ingenious plan for getting rid of the germs contained in the air, and of examining the air both before and after it was purified. He constructed two little air-tight cases or houses with two windows and a door in each. He smeared the interior of one of the houses with glycerine and directed a concentrated beam of light through the windows. The beam without and within the house was found to be full of motes, many of these being germs or seeds. The house was then allowed to stand for three days unmolested, at the end of which time all the motes and germs had settled on the glycerine with which the interior of the house was smeared. The motes, germs, and seeds were in this way trapped and secured. When the concentrated beam of light was a second time directed through the windows of the house, the beam which was very distinct outside the house was found to have disappeared within it, clearly showing that the matter (consisting of motes, germs, and seeds) which made the beam apparent outside the house had disappeared from the air contained within the house. This is a more delicate test of the purification of air than that furnished by even the microscope. If sterilised organic infusions were exposed within the house filled with air thus purified, no living forms ever made their appearance. The infusions could be kept perfectly pure and free from vegetable and animal life for months or even years. If, however, portions of the same or similar sterilised organic infusions were exposed in the house containing unpurified air, the infusions swarmed with life in a few days or weeks at latest. The theory of spontaneous generation was thus shown to be false by ocular demonstration.

M. Pouchet, who believes in spontaneous generation, was of opinion "that infusoria originate in a finely molecular, or (as he calls it) proligerous pellicle on the surface of decomposing fluids, without pre-existing cells or germs of any kind, and therefore independently of parents."

According to Dr. Bastian,[2] "In the proligerous pellicle composed of bacteria, embryonal areas gradually appear. As a result of segmentations in these, specimens of *Monas lens*, $\frac{1}{3300}$th of an inch in diameter, more or less suddenly make their appearance; they increase in size, occasionally assume an amœboid appearance for a time, and are ultimately transformed into real amœbæ. A membrane is formed around them and they become encysted, and in the interior of some of them there springs up a progeny of new bacteria, the production of which occasions their final dissolution." He also describes the formation of numerous fungi occurring in the pellicle at the same time.

Professor J. Hughes Bennett, an able advocate for spontaneous generation, conducted a double series of experiments which he classified under two heads: (*a*) Observations by means of the microscope as to the development of infusoria; and (*b*) Experiments directed to destroy the supposed germs in the atmosphere, so as to prevent putrefaction.

Professor Bennett stated his case with great clearness and vigour in 1868 and 1872.[3] As his former pupil and class assistant for two years, I deem it due to his memory as well as to the importance of the subject to give a digest of his labours in his own words. He observes: "No one can carefully watch the mode in which infusoria are developed, without being satisfied that they originate from the coalescence of molecules, and not from ova and spores, as has been imagined. On making a cold or hot infusion of any vegetable or animal substance, covering the vessel with a piece of paper, so as to exclude the dust, and then watching it every twelve hours, the first change visible to the eye is a slight opalescence, and the formation of a thin scum or pellicle that floats upon the surface. This appears at times, varying from a few hours to several days, according to the temperature of the atmosphere or the nature of the infusion. On examining the pellicle or film under high magnifying powers, it is seen to be composed of a mass of minute molecules, varying in size from the minutest visible point to that of $\frac{1}{30000}$th of an inch in diameter. These molecules are closely aggregated together, and must exist in incalculable numbers. They constitute the *primordial mucous layer* of Burdach, and the *proligerous pellicle* of Pouchet. The same pellicle, examined six hours later, shows the molecules to be somewhat enlarged, and these separated by the pressure of the upper glass are already seen here and there to be strongly adhering together in twos and

[1] *British Medical Journal*, January 29, 1876.
[2] "The Beginnings of Life," vol. ii., p. 232, 1872.
[3] *Monthly Journal of Medical Science*, March 1868. "Text-book of Physiology," pp. 46–48, Edinburgh, 1872.

fours, so as to form a little chain. Many twos, also, have apparently melted together, so as to form a short staff or filament—*bacterium*. Twelve hours after this it may be seen that the grouping of the molecules in twos, threes, and fours has become more general, and that several of these form new groups of eight lengthways. Many of them have melted together to produce longer bacteria. At the edges of the molecular mass, and in the fluid surrounding it, may now be seen a vibratile movement in the shorter bacteria, and a serpentine movement in the longer ones, whereby they are propelled forwards in the fluid—*vibrio*. From the second or third to the fifth or seventh days, the vibrios are lengthened, evidently by apposition of groups of other molecules, to their ends. These unite together endways, to form a filament, which may extend a third or half, and in a few cases entirely across the field of the microscope. After a time they may be seen motionless, evidently dead. This occurs at various periods. They now rapidly disintegrate, and thus a second molecular mass or pellicle is produced. In this, rounded masses may be seen to form, which strongly refract light not unlike pus corpuscles, or the colourless corpuscles of the blood. These soon begin to move with a jerking motion, dependent upon a vibratile cilium attached to one of their extremities—*Monas lens*. In a day or two other cilia are produced, the corpuscle enlarges, is nucleated, and swims through the fluid evenly. Varied forms may now occur in the molecular mass, dependent on the temperature, season of the year, exposure to sunlight, and nature of the infusion, all having independent movements. They have been denominated *Amœbæ*, *Paramecia*, *Vorticellæ*, *Kolpoda*, *Keronæ*, *Glaucoma*, *Trachelius*, &c. It is unnecessary to follow the development of all the forms that may arise. They originate always long after the primary vibrios are produced, in the secondary, tertiary, or even later molecular masses, resulting from the disintegration of previous forms.

"At other times, it happens that the molecular mass, instead of being transformed into animalcules, gives origin to minute fungi. In this case the molecules form small masses, which soon melt together to constitute a globular body, from which a process juts out on one side. These are *Torulæ*, which give off processes which soon are transformed into jointed tubes of various diameters, terminating in rows of sporules (*Penicillium*), or capsules containing numerous globular seeds (*Aspergillus*). Occasionally filaments are formed from the direct melting together of molecules, arranged longways (*Leptothrix*). Why the molecules should sometimes arrange themselves in long rows, and at others into rounded masses, is probably dependent on varying degrees of limpidity and viscosity. But why both these forms of molecular matter should sometimes possess an inherent power of contractility, and at others not, it is impossible as yet even to surmise. But on the determination of this point, the variations existing between the different kinds of fermentation and putrefaction are evidently dependent. In all these processes, varied forms, whether animal or vegetable, may be seen to arise in a clear fluid, from the coalescence of histogenetic and histolytic molecules, without ova or spores of pre-existing organisms." The appearances presented by Professor Bennett's cultures are represented at Plate iii., Fig. 1, p. 6; and at Plate iv., Figs. 1 and 2, p. 7.

Professor Bennett kindly gave me frequent opportunities of studying the phenomena above described, but it appeared to me that sufficient care was not taken to exclude the germs in the air from the infusions: covering them with a piece of paper was not sufficient. I, therefore, came to the conclusion that the true explanation of the phenomena witnessed was given by Lord Lister in 1873.

Professor Bennett describes with commendable brevity the means taken by him to destroy the germs in the air so as to prevent putrefaction.[1] Before giving the results of his own experiments, he explains that "Schultze, in 1837, after heating an infusion to the boiling point, connected it with two of Liebig's bulbs, one containing sulphuric acid, and the other concentrated solution of potash. The air forced through these liquids he thought capable of destroying the atmospheric germs.

"Schwann also, in 1837, forced air, with the same view, through metallic tubes heated to redness; and found, when so calcined, it occasionally prevented infusorial growth. . . . Schraeder and Dusch, in 1859, filtered the air through cotton before bringing it in contact with organic fluids. They found that some did, and others did not, undergo putrefaction."

Professor Bennett continuing says: "In 1863, I determined to try the effects of all these destructive agents, with the exception of the first, at once, and with the greatest possible care.

"On the 17th and 18th of October 1864, and on the 3rd and 13th of October 1865, I performed the following experiments in my laboratory, with the assistance of Dr. Argyll Robertson:—

"Decoctions of liquorice root, of tea, and of hay were kept at the boiling temperature in a porcelain basin, over a gas flame. Flasks filled with and inverted in the boiling fluid had air pumped into them to the extent of three-fourths of their volume which had passed through (1st) a U-shaped tube containing liquor potassæ; (2nd) a hollow glass ball containing gun-cotton; (3rd) Liebig bulbs, containing sulphuric acid; and (4th) another U-shaped tube with sulphuric acid. All the bent tubes were filled with fragments of pumice-stone to break up the air, so

[1] Op. cit., pp. 433, 434.

as to prevent the possibility of any germs passing through in the centre of bubbles. The bent glass tube leading from the last U-shaped tube, filled with sulphuric acid and pumice-stone, was also filled with the acid, so as to destroy any germs that might be supposed to adhere to the interior. After the air so prepared had entered the flask, corks which had been for some time boiled in the infusion were, by means of iron forceps, inserted into the necks of the flasks, and the entrance of fresh air prevented. Further, on removing the flask from the boiling infusion, the cork and neck were hermetically closed by plunging them into melted sealing-wax. . . . The results were that the infusions in all the flasks in contact with ordinary air were rendered turbid or covered with fungi in from six to twelve days; whereas all the infusions which were exposed to the prepared air also became turbid and contained fungi, but at periods varying from four to nine months. When the fluid was examined microscopically, bacteria and vibriones were always found. It was also found that rarefied air delayed the appearance of these infusoria and of turbidity of the fluid. . . . In the numerous experiments made by Dr. M'Kendrick in 1870, 1871, and 1872, it was found that if the fluid be introduced into a flask, boiled, the neck drawn out, bent so as to form numerous acute angles, and the fluid again boiled, it will remain free from turbidity, or the appearance of bacteria or vibriones, for many months, but ultimately the change occurs. The bendings of the tube appear to delay the occurrence of putrefactive changes, but not entirely prevent it. . . . These experiments, on the whole, appear to me to be totally adverse to the atmospheric germ theory, and to indicate that the production or non-production of infusoria depends, for the most part, on the temperature, chemical constitution, density, and other physical properties of the air, rather than on living organisms there, which are developed in the fluid. Still, in every series of experiments, there are one or two exceptions."

It will be noted that in Professor Bennett's experiments the effect of sterilising and excluding, or partly excluding, the air from the infusions was greatly to delay the appearance of living organisms in them. This circumstance of itself goes far to prove that the air had something to do with the production of life in the infusions. Moreover, it is admitted that "in every series of experiments there are one or two exceptions." These exceptions of necessity vitiate the conclusions.

The germs of the lower plants and animals have, in many cases, extraordinary powers of vitality, when exposed to extremes of heat and cold. Dr. Bastian states that plant and animal germs in organic fluids, hermetically sealed while boiling, will stand a temperature of 300° Centigrade without being destroyed, and M. Pasteur narrates how, out of twenty flasks containing boiled infusions from which the air had been expelled, and which were opened by him in intense cold on the Mer de Glace at Montanvert on the Jura, infusoria appeared in five of the flasks.

It is to be regretted that in all the experiments made with a view to settling the question of spontaneous generation in the affirmative, *organic* infusions were employed. These infusions, composed of diluted milk, raw eggs, chopped flesh, gelatine, tea leaves, hay, turnips, and other organic substances, have in themselves the elements of life, and form the best possible materials for the development of rudimentary organisms from germs existing in the infusions or floating in the air. The arguments in favour of spontaneous generation would be much stronger if the advocates of the theory in their experiments discarded everything organic, and relied exclusively for their results on substances which were strictly *inorganic*, or, at least, produced by the physicist and chemist as apart from life, in the laboratory.

It is next to impossible to terminate an old feud or an old controversy, and, as a consequence, the theory of spontaneous generation is ever and anon revived. The theory, it was thought, derived very substantial support from the advances made in modern chemistry, whereby it was affirmed that organic substances hitherto believed to be vital products could be produced artificially in the laboratory. Mr. Rainey,[1] Mr. Bridgman,[2] Professor Bennett,[3] and Mr. Montgomery,[4] made important advances in this direction, but it has to be admitted that the artificial imitation of natural products affords no proof of the production of life in the aggregate as we know it. It cannot, moreover, be determined that the artificial products are really identical with the natural products, and the important fact remains, that no physicist or chemist has been able hitherto to produce life, or anything even remotely resembling it, in the laboratory.

Quite recently (1905) Mr. J. Butler Burke (Cavendish Laboratory, Cambridge) has directed attention to experiments made by him with bouillon (a form of weak beef-tea or gelatine) and radium. His belief is, briefly, that if sterilised bouillon be exposed to the action of radium in glass tubes plugged with cotton wool, living corpuscles, or what he designates *radiobes*, are produced. The exception already taken to the employment of *organic* infusions in experiments intended to establish spontaneous generation applies to Mr. Burke's experiments. Why not employ *inorganic* products? There is another difficulty. It is far from certain that the bouillon was perfectly

[1] "On the Mode of Formation of Shells of Animals, of Bone, and of several other Structures, by a Process of Molecular Coalescence," &c., by Geo. Rainey, M.R.C.S. London, 1858.

[2] "On the Absorption of Bone and Dentine."

[3] *Journal of Anatomy and Physiology*, vol. i., p. 392, 1867.

[4] "On the Formation of so-called Cells." London, 8vo, 1867.

sterilised. Lastly, the experiments made were far too few in number to supply reliable data for settling such an important problem.

I have carefully read his several communications, and examined the various figures given in illustration, but have had no opportunity of examining his microscopic specimens.[1]

So far as I can make out, we are no nearer the goal of spontaneous generation than before. Mr. Burke is by no means certain of his conclusions, and, until they are corroborated by himself and by other and independent workers in the same field, they must be accepted tentatively and with extreme caution. It is, moreover, exceedingly doubtful whether the results obtained by him have not been obtained by others before him. His corpuscles or radiobes greatly resemble minute bodies found over forty years ago by Dr. Rainey, of St. Thomas's Hospital, London, in fluids where carbonate of lime had separated them from a viscous solution. They resemble, in some cases, dumb-bell crystals as seen in Plate i., Figs. 6 and 8, p. 3, and, in others, round carbonate of lime crystals from a viscous fluid as depicted by Professor Bennett (Plate iv., Figs. 1 and 2, p. 7).

The following is Mr. Burke's account of the supposed new living bodies and their mode of production: "By means of radium and sterilised bouillon placed together in a test tube I have succeeded in getting cultures which present many of the appearances of vitality, such as growth and subdivision. It is only within the last three years that the idea of spontaneous generation has been at all in my mind. It was really the result of experiments I had been carrying on for the last ten years both here (Cambridge) and in Manchester in the phosphorescence of cyanogen, which Plüger declared had the elements of life. . . . It seemed to me a very reasonable thing that if cyanogen was a living thing it ought to grow in culture media. So I tried to cultivate it, but the result was negative.

"Then observing that radium had several qualities in common with cyanogen—it is highly excitable and contains a vast store of energy—I made experiments with radium.

"I tried radium with sterilised bouillon, the ordinary culture medium, placing them together in a test-tube —the radium being in actual contact with the bouillon—and after a day or two I got these cultures. . . .

"Subcultures of these were made, and although they are seen to grow slightly, they do not grow as bacterial subcultures should. That is the point where it is first possible to differentiate them. Another reason is that they are soluble in water, while bacteria are not.

"In addition, when you examine these atoms through the microscope you see a distinct indication of growth and segregation. When they reach a certain size they subdivide.

"That seems to me to show very clearly that they are not crystals either. Possibly they are a primitive form of life. Nearly everything is radio-active. The earth itself is, and in some suitable medium life may have originated on the earth in that way.

"The great difficulty about the origin of life, as Huxley found, is that life does not originate in organic bodies which have been sterilised. . . .

"We cannot attempt to discuss the original cause—that is beyond the scope of science altogether. But to explain things on the principle of continuity of nature seems to me to reveal the harmony of the universe in the works of the Almighty.

"Should my experiments prove the possibility of 'spontaneous generation,' it is a principle not in the least destructive of the deistic conception of the universe. In fact, if it can be shown that dust and earth can produce life on account of radio-activity, it would only confirm the truth of Biblical teaching. That, it is obvious, cannot be proved in our time, because the radio-activity of the earth is so small that it might take thousands of years to produce life."

With regard to Mr. Burke's statement "that it might take thousands of years to produce life," it is necessary to point out that the statement is subversive of his theory of spontaneous generation, inasmuch as he believes he can demonstrate the production of life by means of his radio-bouillon mixtures in a few days. According to his figures, his living corpuscles or radiobes appear in from three to four days: after about a week they each display a nucleus: after about a fortnight they proceed to divide and throw out a portion of their substance. This sudden development of life by artificial means savours too much of a creation to be trustworthy, and I must be excused if I reserve my judgment, and refuse to accept such a momentous conclusion on such slender evidence. I am, however, not alone in my misgivings.

Sir John Lubbock (Lord Avebury) says: "The properties of radium are no doubt marvellous, but I confess I should have expected that any life-originating process would have required a considerable amount of time as a necessary element."

[1] The *Daily Chronicle*, June 29, 1905; letters in *Nature* about same time; article, "Origin of Life," *Fortnightly Review*, September 1, 1905, &c.

Dr. Bastian, the staunchest supporter of spontaneous generation in modern times, observes: "In reference to the very interesting experiments of Mr. Burke at the Cavendish Laboratory, Cambridge, and the nature of the bodies discovered by him, it is needful to bear in mind two things:—

"1. That, as shown by George Rainey in 1858, in his work 'On the Mode of Formation of the Shells of Animals, &c.,' crystalline matter undergoes very important modifications in shape when the crystals form inorganic or viscid solutions. When carbonate of lime is slowly precipitated in viscid solutions of gum, albumen, or even glycerine, a combination takes place between the saline matter and the medium, so that instead of octahedral or hexagonal crystals being formed, spherical or ovoidal calculi are produced, built up by the superposition of concentric layers; and the initial forms of these bodies as they separate from the mother liquid are almost exactly like some micro-organisms, as shown in one of Rainey's figures. Some of the bodies there shown have an appearance suggestive of fission, but which is probably due rather to coalescence of two separate bodies. Some of them also contain nuclear-like particles.

"2. We must not forget that an actual process of fission may occur in certain not living forms of matter, as was shown by the celebrated French microscopist, Charles Robin, in 1859, in one of the 'Memoirs of the Academy of Medicine.' He found such phenomena especially marked with certain fatty extracts obtained from the blood, when mixed with water or with albuminous fluids. He says: 'From masses of these extracts there may be seen projecting and elongating under the eyes of the observer filaments having a tubular appearance, either straight, bent, undulating, or spiral in their arrangement, like those of various anatomical elements. Sometimes the extremities of some of these tubes become constricted and moniliform, and the constrictions go on so as to produce complete division with separation of little hollow spheres, just as in the production of conidia from the tubular cells of various moulds, oidium, &c.'

"Again, when speaking of small spherical masses of these extracts, Robin says these may be seen under the microscope incessantly to change their form, as a result of alternate partial constrictions and dilatations. These constrictions or contractions even go so far as to produce a complete division of certain globules into two, in the same way that one may see division brought about by gradual constriction in certain vegetal or animal cells. [These points are illustrated at Plates i., ii., iii., and iv., pp. 3, 5, 6, and 7.]

"An account of these observations was reproduced by Robin in his 'Traité du Microscope' in 1871.

"Without attempting to detract from the interest attaching to Mr. Burke's experimental results, it seems clear that both of the above-mentioned sets of observations have an important bearing upon the interpretation of the nature of the bodies which he has discovered. Further work will, doubtless, enable him to show whether the bodies in question are really living things or modified forms of crystalline matter."

Sir Oliver Lodge remarks: "The results are of such great interest that it will be necessary to anybody who obtained them to be very sceptical himself, and until they are repeated and more understood it is safer not to imagine that one has any opinion concerning them.

"On the face of it, it looks as if some complex molecular aggregates had been formed, which, as I have indicated in an article on 'Life,' which appeared in the May number of the *North American Review*, will probably be found on the road towards organic evolution. . . . Their susceptibility to stimuli and their power of assimilating food would have to be established, and it is not to be supposed that those functions have as yet been detected without previous life-germs. . . . But people must not be surprised if in the course of years something is done in the laboratory which may be properly considered to be of the nature of spontaneous generation, although it may be safely said that all the many attempts in that direction hitherto have conspicuously failed."

Professor John G. M'Kendrick states: "The difficulty will be to prove that the fluids employed by Mr. Burke were, in the first instance, completely sterilised. As in all other experiments salts of radium are found to have a destructive action on microscopic organisms, it seems wholly improbable that it could induce such changes in organic matter as to lead to the production of new beings."

Dr. Metchnikoff avers: "It is much too early to draw any conclusions. . . . It will require a great deal of corroboration to make me accept Mr. Burke's results as proof of spontaneous generation."

Sir William Ramsay, who has devoted considerable attention to the subject, is disposed to regard Mr. Burke's "radiobes" as gas bubbles which burst and reproduce themselves. He writes as follows: "Dr. Bastian has contended and still contends, that the same spore does not always produce the same organism, but I doubt if even he would maintain now that life spontaneously arises in carefully sterilised liquids. The balance of evidence against such a supposition is now immeasurably strong. It has become a commonplace that liquids in which minute organisms termed microbes can flourish and increase may be purified from such organisms by heating for a longer or shorter time to a relatively high temperature, and that if protected from the ingress of microbes or their spores by a plug of cotton wool, or by a long narrow tube, they manifest no sign of life, however long they are kept."

Mr. W. A. Douglas Rudge, of the Woodbridge School, Suffolk, furnishes yet another explanation. In a communication to *Nature* of date November 23, 1905, entitled "Action of Radium Salts on Gelatin," he says: "On continuing the experiments detailed in *Nature* of October 26, I found that lead and strontium salts produced the same results upon gelatin as was the case with radium, but the strontium 'growths' were much less vigorous than the others.

"On considering the results, it is seen that the metals named are those which form insoluble sulphates, and it occurred to the writer that the 'growths' were simply a precipitate of some insoluble body formed by the action of the salts used upon the gelatin.

"Various solutions of bouillon and gelatin were prepared, and to each were added a few drops of solution of radium or barium or lead salts, with the result that in each case a precipitate was obtained which on careful examination was found to consist of a sulphate, or at all events an insoluble compound containing sulphur.

"The precipitate produced by the radium salt was tested to see whether it was in any way different from that produced by the barium salt, but, with the exception that it was radio-active, it appeared to be similar in all respects. It was insoluble in strong acids, and gave a sulphide on fusion with sodium carbonate on charcoal, and qualitatively contained no other metal than barium.

"In making the experiments, a few drops of the gelatin were placed on a glass slide, and particles of radium and barium salts added as described in the last communication. The 'growths' appeared. Some solution of barium nitrate or radium salt was now added to the liquefied jelly. The usual precipitate appeared, and this was filtered off through a porous tube. The clear jelly was now tested with radium and other salts, and no 'growth' could be seen even after seven days.

"I think this proves very conclusively what the alleged 'growths' are, namely, that they are nothing more than finely divided precipitates of insoluble barium salts. I have examined these precipitates with the highest microscopic power at my disposal, and cannot, in any case, perceive that there is anything of the nature of cell division occurring.

"Of course, many pairs of particles may be found, but the grouping must be purely fortuitous.

"As there is only a limited amount of matter in the gelatin which can be precipitated by the radium, a concentration occurs at the point of contact of the salt with the gelatin, and then slow diffusion of the remaining salt takes place downwards, and this might give rise to the idea that the thing was really growing."

Lord Kelvin, the *facile princeps* of physicists, was emphatic in his words of warning regarding the too ready acceptance of new theories of life.

HEREDITY AND DESCENT—TRANSMISSION OF PECULIARITIES NATURAL AND ACQUIRED—FORMATION, USE, AND DISUSE OF ORGANS

All the knowledge we possess of existing plants and animals, as well as the geologic remains of pre-existing flora and fauna, points to a succession, more or less interrupted, of living forms resembling each other, and, within limits, related.

Plants and animals are arranged for the most part in an ascending series; the lower approaching towards but never actually merging into the higher. The lower precede the higher in the order of formation, and they present types or standards from which they occasionally vary slightly, but to which they ultimately return. There is a tendency to improvement in the types which is more apparent than real; the improvement occurring in the individual rather than in the race. Thus in all ages there have been examples of outstanding organisms which have, as it were, sprung from the ranks and sooner or later returned to them. This is well seen in human communities, where leaders of no particular family come to the front for one or two generations and then disappear in the common stock. It is not a case of power confined to particular families for indefinite periods, but of power proceeding from particular members of families and merging and disappearing in the families at short periods. This means rather an advance in the individual than in the race, and does not interfere with the general configuration and constitutional peculiarities of given types. If there was a continual advance in man and other organisms a time would ultimately arrive when the originals would largely or wholly have disappeared in the accumulations of improvements. There would be an end of persistency and fixity of type, which, so far as is known, does not occur. Improvement in no instance results in obliteration. The corrective is to be found in reversion, or the tendency to breed back; the improved individuals sooner or later returning to their original level in the scale of being. Examples are not wanting where the higher forms deteriorate and assume the charac-

teristics of the lower forms, as happens in parasites. There is, as it were, an occasional breeding upwards, and a breeding downwards—a fluctuation, so to speak, between the more highly organised and the rudimentary forms.

Differentiation in plants and animals means complexity, but it does not follow that the more complex plants and animals are more perfect than the more simple ones, when the end for which they were created is considered. The term "perfection" as applied to plants and animals is, strictly speaking, relative, and it becomes a question whether all kinds of plants and animals, and all modifications thereof, are not perfect when all the circumstances under which they were produced, and their environment and ultimate function, are taken into account. The unicellular plants and animals are, or may be, as perfect in their way as the more highly differentiated plants and animals. So far as the duration of life is concerned the lower forms have, in many cases, the advantage; a tree may live a thousand or more years; animals rarely living a hundred years. The simpler forms are also more tenacious of life; low vegetable and animal types resisting extremes of heat and cold which are fatal to the higher types. If the term "perfection" can be applied to the highest plants and animals, it certainly cannot be withheld from the lowest. Complexity of structure and function do not necessarily make for perfection in the broad and general sense. If the inorganic and organic kingdoms be regarded as a whole and as complemental parts of each other (and they must be so regarded if they are to be scientifically considered), the atom and the molecule, the cell and the cell tissue, must all be looked upon as perfect within their appropriate spheres. This view elevates the lower forms without in any way depreciating or detracting from the higher ones. It is necessary in the present state of science to give more attention and higher values to the probably misnamed rudimentary plants and animals.

The rudimentary plants and animals have always existed, and in their special domain are as useful in the great scheme of nature as the highest plants and animals. This will be regarded by some as a levelling down and destructive doctrine. As a matter of fact, it is a fundamental doctrine, and one which cannot be set aside. If rudimentary plants and animals exist now and have existed from the beginning of the world, it is obvious that they have to be reckoned with, and, if possible, understood. They are the precursors, though not the progenitors, of the higher plants and animals. The lower plants and animals form zones or strata of life which are localised in time and space, and are necessary to the existence of the higher plants and animals, as they supply the food and other conditions which keep the higher plants and animals in a state of health.

The existence of the zones or strata referred to is proved by the geological record and by palæontological research. It is also proved by the distribution of plants and animals on the earth's surface at the present time. That the order of nature is not different now from what it was in prehistoric times is a matter of certainty. If, however, the lower rudimentary forms are permanent, it follows that they are as much a necessity as the higher forms, and, in this sense, as important.

The fact that there are zones or strata of rudimentary plants and animals goes far to prove the separate creations of types and the stability of the organic kingdom. If, as evolutionists believe, all plants and animals tend to differentiate and to merge by insensible gradations into something higher than themselves, a time would naturally come in the history of the world when no lower forms would be left, unless, perchance, they were being constantly supplied by a supposed spontaneous generation, in which very few, if any, believe. The history of the earth is wholly opposed to such a view. The lower forms are as numerous now as they have ever been, and it may be confidently asserted that they will continue as long as the present order of things lasts. It is certain that the lower plant and animal forms have the power of reproducing themselves equally with the higher forms, each after its kind, trifling variations and fluctuations being possible. These variations (and this is important) are not cumulative in nature as they are in artificial breeding. Plants and animals, from the lowest to the highest, are not fundamentally changed by variation. If they depart from a special type in a particular direction and at a particular period because of environment and altered conditions as regards food, locality, climate, &c., they revert to it subsequently, when the original and natural conditions recur. It is not an indefinite departure, and it is here that heredity and descent, strictly speaking, come into operation. The doctrine of heredity is founded upon the fact that the offspring resembles its parents, but it is obvious that if man, as has been stated by Mr. Darwin and others, be regarded as the genealogical or ultimate product of an oyster or other mollusc, the *raison d'être* of the doctrine disappears. A man in no respect resembles an oyster, either in structure or function. Heredity ceases to be a recognisable quantity. Of course, those who hold an opposite view will say that, given a sufficient number of forms and sufficient time for the modification of these forms, the resemblance will be continued. This, however, is a mere begging of the question at issue—a *petitio principii* pure and simple. Illimitable changes in illimitable time might, if endless variation be conceded, accomplish anything the most extravagant dreamer could imagine, but fancies can never take the place of facts in inductive reasoning.

It is readily conceded that plants and animals in a state of nature ever and anon vary slightly. The tendency, however, to revert to their original acts as a corrective, and prevents the accumulation and trans-

mission of variations, and so preserves the types. Heredity, in nature, applies less to variations than to root stocks; the variations not being cumulative. It is otherwise under cultivation and domestication. Here everything is artificial. Variations are seized upon and perpetuated by making plants and animals more or less unnatural; by cultivating and developing certain parts of plants and animals; by restricting the area of reproduction; by turning the streams of life into particular channels; by protecting the particular life thus produced; by supplying artificial foods, artificial heat, &c.; by, in short, protecting plants and animals from natural competition, and preventing the healthful exercise of their bodies and bodily functions as a whole. Under these circumstances, variations, within limits, are cumulative and transmissible. The stronghold of heredity is in artificial breeding. In cultivated plants and animals the variations are accumulated, transmitted, and perpetuated, but this state of things exists only so long as the artificial conditions are maintained. As soon as they are departed from, reversion to original types begins, and gradually the *status quo* is re-established. Heredity, in nature and natural reproduction, is confined to resemblances in types apart from variations and varieties; in artificial breeding it includes the types and the variations and varieties as well. The two kinds of heredity are widely different. The heredity of nature simply means *like producing like;* the heredity of art means *like producing like plus the element of unlike or variation.*

What is objected to by those who are opposed to evolution and natural selection is not occasional slight variation, but the manufacture, so to speak, of the highest plants and animals out of the lowest *in an unbroken series,* and the modification or alteration of plants and animals by externalities, such as locality, environment, food, climate, &c., beyond recognition. Under such circumstances, heredity and descent are negligible quantities, and cannot, strictly speaking, be regarded as the direct outcome of reproduction.

The law of heredity is best studied in animals (preferably domestic) where there is a nervous system, as in this case there are, in many instances, modifications both of external form and mental peculiarities to be considered. To take examples, there are short and long-legged dogs, large and small horses, sheep which, at parturition, throw twin or triplet lambs, men with six instead of five digits, women with more than two mammæ, &c.

There are also peculiarities of disposition, temper, and intellect. Animals and men may be mild tempered or vicious, affectionate or the reverse, stupid or clever, and so on. All these traits, corporeal and mental, may be transmitted, and it is a common saying that the offspring, in the majority of cases, may be trusted to father itself.

In the breeding of stock, desirable peculiarities of form and disposition are selected, and, in many cases, successfully transmitted. This is a wholly artificial process. No corresponding process exists in nature. Plants and animals artificially bred do not lose their identity any more than plants and animals in a state of nature; they are not converted into new and different beings. If left to themselves they invariably revert to their originals; the chrysanthemum returns to the daisy, and the several kinds of pigeons to the blue rock pigeon.

As regards animals with a nervous system, there are those who believe that acquired habits and powers are, up to a point, transmitted, and that training, whether physical or mental, reappears to a slight extent in the offspring. Thus well-bred sheep-dogs and hunting dogs take to their work naturally, and require little or no training. Race-horses compete with each other in the paddock; and great mental capacity is not confined to one generation. Education proceeds on the capacity for progress in the individual and in the race. The view here enunciated is tentative, for it must be admitted that well-bred animals occasionally throw mongrel offspring, and highly cultivated, intellectual parents give birth to foolish, unintelligent children. Conversely, ordinary under-bred men and animals, ever and anon, produce the highest possible types. Over-breeding and over-training, if long continued, are apt to result in degeneracy. The city has to be supplied with new blood and brain from the country. Professor Weismann holds strongly to the non-transmissibility of acquired characters, and, on the whole, I agree with him. The so-called instincts are the outcome of intelligence, experience, and habit transmitted from parent to offspring through long periods. Instincts, it is well to remember, have their origin in intelligence, a fact, if overlooked, tending to confusion. Habits, corporeal and mental, are born of intelligence and repetition. The acquired knowledge of one generation is, within limits (by the aid of printing, &c.), handed on to a succeeding generation, and each generation may add to, or take from, the common stock. Instinct was not originally, in essence or in fact, a mere blind repetition, and it is questionable if, even at the present day, it is so. There are good grounds for believing that what is called instinct, in common parlance, is being continually modified. The transmission of acquired properties is still *sub judice.*

Animals accredited with instinct do not always act in precisely the same way. Ants, for example, while they build their nests on a general plan, often deviate from it. The same is to be said of bees and birds. Bees, not unfrequently, alter the shape of their honeycombs; and birds, in many cases, make elaborate and extensive foundations before the nest-building proper begins. With our present knowledge, instinct cannot be dissociated from

intellect. It is, strictly speaking, an intellectual gift of heredity. It is on a level with the so-called automatic actions in ourselves. Automatism, however, in man is fundamentally intellectual in its nature. It is the result of voluntary effort often repeated and long continued. It only becomes involuntary and unconscious after constant repetition during protracted periods. Instinct, when so regarded, is rescued from being a peculiarity of the lower animal forms, and establishes a mental connection between the lower and higher animals which strictly corresponds with the development or degree of differentiation in the nervous system. As it is not possible to distinguish between the different kinds of nervous matter in the lower and higher animals, neither can a line be drawn between instinct, intelligence, and reason proper. It is a question not of kind but of degree. *Cæteris paribus* the larger the brain, and the more highly differentiated the nervous system, the greater the intellectual activity and power. In the higher, philosophical sense, there is no such thing as instinct.

While intellect culminates in man, it is not possible to say where it begins in animals. Similar remarks may be made of consciousness.

While the nervous system in the adult is credited with the control and harmonious working of all the other systems of the body, it exerts next to no influence in the production, in the embryo, of the several organs composing the body. As a matter of fact, it requires to develop and grow *pari passu* with them. No manifestations of intellect, or consciousness, or guiding power are discoverable in the embryo and fœtus. They come afterwards as development proceeds and the adult condition is reached. The nervous system makes itself felt according as it grows, and according to the degree of differentiation attained by it. The function of the adult nervous system is to connect and co-ordinate the several organs and bring them under the influence of one or other of the great nerve centres, especially those of the brain and spinal column.

That the nervous system has nothing to do with the production of the organs of the body is proved by this, that in the anencephalous fœtus, where there is no brain, the body and organs are well developed.

While the production of organs is not the work of the nervous system, neither are they chance products due to environment and external conditions. On the contrary, they are all provided for and exist in a latent or potential form in the germs, seeds, and eggs of plants and animals. Heredity, reproduction, and the formation of organs are essentially and directly the product of atoms, molecules, and cells; the atoms forming the molecules, the molecules the cells, and the cells the tissues in unvarying sequence. The organs are formed to produce certain important results; to achieve certain desirable advantages; and especially to connect the individual with the world it inhabits.

The organs are original structures, cunningly devised and cunningly constructed. They are means to ends, and the ends are never lost sight of from beginning to finish. They are not produced by accidental increments accumulating and extending over vast periods. They are in no way due to "natural selection" as advocated by Mr. Darwin. In reality, they appear ready formed at certain stages in the development of plants and animals. They, moreover, appear spontaneously and independently; in other words, they are the equipment and outfit of life as conferred by the Framer and Ruler of the universe, as contra-distinguished from every form of irritability, stimulation, and environment.

The leaves and roots of plants were not made by the air and soil. On the contrary, they were formed to extract nourishment from both. The teeth and stomach were not made by the food, the heart by the blood, the lungs by the gases respired, the kidneys by the fluids discharged, the muscles by movements, or the brain by thinking. Similarly, the eye was not made by the light, and the objects which the light reveals. It was made to perceive light, and everything seen by its aid, near and remote. The ear was not formed by sounding bodies and sound waves. Its function is to feel sounding bodies at a distance by the instrumentality of rhythmically vibrating atmospheric particles. The smelling organ was not made by odoriferous motes floating in the air; it is specially fashioned to detect their presence. Similarly, the taste apparatus was not created by sapid substances in a state of solution; it is developed to recognise them and give pleasure in eating and drinking. Lastly, the sensitive skin which envelops the majority of animals was not made by the air, water, or anything with which it comes in contact. In reality, it is expressly formed to give animals protection and a knowledge of their immediate surroundings. All the sense organs which are modifications of skin have a similar object. Their primary function is to connect or gear the individual to matter near and at a distance, and to distinguish between the grosser and finer kinds and qualities of matter. In a word, the sense organs enable the individual to appreciate and realise its surroundings; the amount of information conveyed increasing according to their complexity. All this indicates design, and design of a high order. The individual is made for the world: in other words, the inorganic kingdom is, so to speak, the objective of the individual; but the inorganic kingdom does not of itself make the individual. The organic and inorganic kingdoms owe their existence to one and the same First Cause, and the one is adapted to the other.

The organs of plants and animals are special endowments, and as such are fundamental. They form the machinery by which life carries on its work, and without which it would come to an end. If organs had to be formed by fits and starts accidentally, and not by predetermined vital acts, there can be little doubt they would be few in number, and probably deficient as regards elaboration and finish.

Life without its organs would be a misnomer. For the wisest of purposes each organism is made superior to its surroundings, and whatever changes occur in plants and animals begin and end in themselves under supervision.

It has been stated that organs appear and disappear with use and disuse; that they are formed by external conditions, that is, by contact with external substances, and by artificial stimulation, and that, if the external conditions referred to be withdrawn, they gradually cease to exist. It is argued that if an organ disappears by *disuse*, it ought to appear, or come into existence, by *use*. This, however, does not follow. Organs, once formed, doubtless increase in size by use or training, and decrease by inactivity. There is, however, a great difference between the legitimate use of an organ and its abuse or neglect. The one is a normal, the other an abnormal condition. The blacksmith's arm increases in volume and strength by wielding the hammer, and the mountaineer's legs become sturdy from continuous hill climbing. Palsied limbs, on the other hand, become attenuated and feeble for want of exercise. The sight of ponies worked in dark pits becomes feeble, and the eyes of cave fishes are useless as seeing organs, and comparatively small in size. Disuse tends to dwarf and destroy organs. Disuse is, in a sense, equivalent to abuse. If an organ is not required and is never exercised, it is bound to deteriorate, and this accounts for the remnants of structures found in animals with, apparently, no function. Of such is the vermiform appendix in man. The fact that an organ improves by use and deteriorates by disuse throws no light on the manner of its production, and it is more natural to believe that plants and animals form their own organs during the process of development than that they are formed for them by things outside of themselves. There is conclusive proof of this in the fact that the organs are formed before they are required, and in anticipation of the functions to be discharged by them. Thus in animals, the alimentary canal is constructed to contain and digest food when it reaches it; the lungs to inhale pure and exhale impure air; the heart to receive and propel blood; the kidneys to deplete the blood of noxious products; the liver to secrete bile; the mammæ to provide milk; the muscles and bones to produce movements; the nerves to regulate them; the skin to protect; the senses to give information regarding external objects, &c. Plants and animals develop spontaneously and independently, and apart from irritability, stimulation, and environment in every form. They are specially designed and fashioned to perform distinct rôles, and are, in no sense, the products of circumstances, either in their beginnings or during their lives.

Those who hold that organs are, to a large extent, accidental, and the result of environment and artificial stimulation, can give no satisfactory explanation either of their inception or their continued growth and development. They cannot even guess why they should be formed. The sense organs, and in particular the eye and ear, bewilder and perplex them, for they are forced to admit that so long as an organ is developing and is of no use to its possessor, it is a mere incubus and a source of weakness, since it appropriates the material and force of the individual without giving anything in the shape of compensation. It is only when an organ is fully matured that it becomes useful. The electric organ in the great South American electric eel (*Gymnotus electricus*) weighs about a third of the whole body of the animal. According to the evolutionists, and those who believe in "natural selection," it must have been nourishing and dragging about this heavy growing electrical apparatus for untold ages until it acquired the necessary size and strength to make it serviceable. The theory of natural selection utterly fails in such a case, as it maintains that only *useful* variations are seized upon, preserved, and transmitted. So judged, the electrical organ could never either have been formed or perpetuated.

What is true of the electrical organ is true of all other organs, be they small or great, simple or complex. The evolutionists and the Darwinians endeavour to escape from the horns of the dilemma by saying that organs are found in different stages of perfection in different animals. The reply is obvious. The organs, in all animals, whatever the degree of perfection attained, are equal to their work, and are carefully adapted to meet the requirements of each particular case. They also fall back on the development of organs *in utero*. Their case fares no better here. As explained, organs are formed *in utero* before they are required, and before they can be of any possible service to their possessors. They are, moreover, not formed piecemeal by accidental increments at odd times, but continuously with other organs; each organ forming a part, and a necessary part, of a planned whole. The only explanation that can be given of their production is that they are original endowments conferred by an intelligent First Cause and Designer, Who saw the end from the beginning, Who makes everything work together for good, Who endows plants and animals with properties and powers which make them superior to their surroundings, and which enable them not only to take, but also to maintain, their places in nature, time, and space.

§ 217. A First Cause Necessary to Life—Life Transmissible—Types of Plants and Animals versus Evolution and Spontaneous Generation.

There are two great views of life; the one that it is a something superadded to and distinct from mere inorganic matter as we behold it in the physical universe; the other that it is the spontaneous product or outcome of inorganic matter under peculiar circumstances and conditions. The former view involves the existence of a Creator Who, having made the inorganic kingdom and placed it under law, proceeded subsequently to vivify certain portions of it to constitute what is known as the organic kingdom—the kingdom of plants and animals. This He also placed under law. The two kingdoms, while distinct in one sense, interdigitate and form complemental parts of each other. The other or second view of life denies the existence of, and dispenses with, a Creator or First Cause. It attributes the inorganic and organic kingdoms to the operation of blind chance: to matter fashioning itself; to matter assuming movement; to matter assuming life and building up plants and animals up to man. Those who maintain the latter view ask—and they are quite entitled to ask—who made the Creator? This is, of course, an extreme position to take up, and when taken up little can be made of it, as it is unnatural to suppose that matter made itself, and that life entered into matter spontaneously. Moreover, the countless examples of cause and effect which are everywhere witnessed in the inorganic and organic kingdoms indicate sequenec and design difficult to account for apart from the highest conceivable order of intelligence. The two views referred to each claim as their advocates men of outstanding ability in philosophy, science, and letters. The question of creation, and life as a consequence of creation, is not one likely to be solved in our day, but, so far as existing evidence goes, the weight of testimony is, it appears to me, in favour of a Creator, and creation as a progressive work. I cannot conceive of the present order of things existing apart from design and the supervision of an All-wise Providence. Those who take the opposite view regard every creative act as a capricious interference with the laws of nature. They deny everything in the shape of design, order, and purpose. All the adaptations in the inorganic and organic kingdoms they trace to a power which they say inheres in matter as such.

The two great views of creation, and life as an integral part of creation, may be briefly stated.

Newton and Swedenborg, as I have already explained, support the first, and Haeckel and Tyndall the second view, in the following passages. Newton, when speaking of the formation of the sun and fixed stars, says: "I do not think (this) explicable by mere natural causes, but am forced to ascribe it to the counsel and contrivance of a voluntary agent." In like manner, Swedenborg remarks "that nothing can be truly known of the visible world without a knowledge of the invisible, for the visible is a world only of effects, while the invisible or spiritual is a world of causes."

Haeckel and Tyndall reject a First Cause. They attribute everything to a power inhering in matter as matter, in virtue of which it assumes shape and movement, apart from a Creator and apart from life.

Other writers claim attention. Laplace, the author of the "Mechanism of the Heavens," observes that "Present events are connected with the events of the past by a link resting on the obvious principle that a thing cannot begin to exist without a cause which produces it. This maxim, known by the name of the Principle of Sufficient Cause, extends likewise to events with which it is not supposed to come in contact. Even the freest will cannot evoke them without a determining impulse. We must, therefore, regard the present condition of the universe as the consequence of its former, and the cause of its future, condition."

Dubois Reymond, in an address delivered at the Fiftieth Assembly of German Naturalists and Physicians, indicates boundaries in the investigation of nature. He says: "The knowledge of natural science is no real knowledge. In the attempt to comprehend the constant, to which the mutations in the material world may be traced back, we stumble on insoluble contradictions. An atom contemplated as a minute, indivisible, inert mass, from which forces emanate, is a chimera. In the impossibility of comprehending the nature of matter and force lies one limit to the knowledge of natural science." He then adds: "If we pass over this, the universe is approximately comprehensible. Even the appearance on the earth of life in the abstract, contemplated from the standpoint of the theoretical investigation of nature, is merely the arrangement of molecules in a state of more or less stable equilibrium, and the introduction of an exchange of material, partly by their own elastic force, partly by motion transferred from without. It is a misapprehension to see anything supernatural in this."

Dubois Reymond indicates a second limit as under: "And yet a new incomprehensible appears in the shape of consciousness even in its lowest form, the sensation of desire and aversion. It is, once for all, incomprehensible how, to a mass of molecules of nitrogen, oxygen, hydrogen, carbon, phosphorus, and so on, it can be otherwise than indifferent how they lie or move; here, therefore, is the other limit to the knowledge of natural science. Whether the two limits to natural science are not, perchance, identical, it is, moreover, impossible to determine."

Professor Oscar Schmidt says that "In these last words the possibility is indicated that consciousness may be an attribute of matter, or may appertain to the nature of the atoms. The attempt has of late been repeatedly made to generalise the sensory process, and to demonstrate it to be the universal characteristic of matter, as by Zollner, in his work on the Nature of Comets, which has created such a justifiable sensation. He holds that, if by means of delicately-formed organs of sensation it were possible to observe the molecular motions in a crystal mechanically injured in any part, it could not be unconditionally denied that the motions, hereby excited, take place absolutely without any simultaneous excitement of sensation. We must either renounce the possibility of comprehending the phenomenon of sensation in the organism, or hypothetically add to the universal attributes of nature, one which would cause the simplest and most elementary operations of nature to be combined, in the same ratio, with a process of sensation."

Lazarus Geiger expresses a similar belief. "But how is it," he asks, "if further down, below the world of nerves, a sensation should exist which we are not capable of understanding? And it probably must be so. For as a body that we feel could not exist unless it consisted of atoms that we do not feel, and as we could not see a motion were it not accompanied by waves of light which we do not see, neither could a complex living being experience a sensation strong enough for us to feel it also, in consequence of the motion by which it is manifested, if something similar, though far weaker and imperceptible to us, did not occur in the elements, that is to say, in the atoms."

From the foregoing, it will be seen that there is a tendency on the part of many distinguished men to set aside a Creator or First Cause, design, and vital force. Nothing, however, is gained, and assumption, in the majority of cases, takes the place of argument. Thus Professor Oscar Schmidt, as far as life is concerned, begs the question in the following passage: "We now know that the world was not made by fits and starts, but originated by gradual formations and metamorphoses; we may—nay, we must—infer that, at a definite epoch of refrigeration, life appeared in a natural manner, that is to say, without any incomprehensible act of creation; and during this slow transformation of the earth's crust, we see living beings also gradually increasing, differentiating, and perfecting themselves. Yet more. As was first convincingly proved in detail by Agassiz, one of the most vehement antagonists of the theory of descent, we behold the palæontological or historical series of organisms in the same sequence as the phases of the development of the individual. There are here vast chasms yet to be filled up by future observation, though in many points we must not altogether despair of success. But that the process of palæontological development is, in general, the one indicated, is disputed only by naturalists who, like Barrande, years ago anchored themselves to unalterable convictions in science, as in creed to dogmas. . . . Millions and millions who would turn away indignantly if required to believe that anything not entirely natural occurred in the most complicated machine, in the most elaborate product of the chemical retort, or in the strangest results of physical experiment, are yet disposed to seek a dualism behind the processes of life."

A theory which sets aside creation, which assumes that at a definite epoch of refrigeration "life appeared in a natural manner," and which states that "many thousand cubic miles of the sea bottom consists of a slime or mud . . . a living mass either absolutely formless and undefined or defined arbitrarily and accidentally," is not likely to find acceptance with the more thoughtful and serious students of the present day. It is too vague and visionary to account for even the lowest plant and animal forms, to say nothing of the higher and highest.

According to Oken, "All nature is a process of evolution." In his opinion, "Natural science is the science of the eternal modification of God, that is of Mind, in the world, and is thus in the widest sense, Cosmogony. Everything, when contemplated as part of the genetic process of the whole, involves, besides the idea of existence, also that of non-existence, or position and negation, as it rises into a higher idea. These contrasts include the category of polarity, which manifests itself in motion, the life of all things. The simpler elementary bodies aggregate into higher forms, which are mere higher powers of the former, as their causes. Hence the various classes of bodies represent parallel series, each corresponding with and modifying the order of the other; classes of which the rational arrangement follows with inherent necessity from their genetic coherence. But in individuals, these lower series again become apparent during the period of development. The antagonisms in the solar system of the planets and the sun repeat themselves in plants and animals; and as light is the principle of motion, the animal has the advantage of independent motion above the vegetal organism, which pre-eminently belongs to the earth. Embryology receives its due in a general proposition. 'Animals perfect themselves gradually, adding organ to organ in the self-same manner as the individual animal is perfected.' But in Man, as the highest animal, the whole animal world is contained; he is the actual Microcosm."

Goethe was deeply imbued with the idea of type. He noted the varying phenomena in plants, and referred the variations to unity and rule.

According to him, "The same organ may be expanded into a compound leaf, or contracted into a simple stipule or scale. According to different circumstances, the self-same organ may be developed into a peduncle or an unfruitful branch. The calyx, by over-hastening itself, may become the corolla, and conversely, the corolla may approximate to the calyx. Thus the most varied structures of plants are rendered possible, and he who in his observations keeps these laws always before his eyes will derive from them great alleviation and advantage. . . . From the seed, plants are developed, ever diverging, and variously determining the mutual relations of their parts."

Here the doctrine of the "Metamorphosis of Plants" is summed up.

Goethe instituted a comparison between the species and genera of insects; the rings of insects resembling the organs of vegetables, as modifications of the same rudimentary organs. In 1796 he broached the idea "of the development of organic beings by the heterogeneous evolution of their fundamentally similar parts" as seen in the caterpillar and butterfly. "Imperfect and evanescent a creature though the butterfly may be as to its species, when compared to the mammal, in the metamorphosis which it accomplishes before our eyes it nevertheless exhibits the superiority of a more perfect over a less perfect animal. This consists in the decisiveness of its parts, the security that none can be put or taken for the other; that each is destined for its function, and remains constant to it for ever."

Goethe next dealt with the Vertebrata or highest form of animals. He saw in the vertebral column a most important structure, a development from rudimentary similar parts; each vertebra, though modified, resembling its fellow. Finally he was able to prove that even the bones of the cranium consist of modified vertebræ, and that all the higher animals up to man possess an inter-maxillary bone. Goethe sought to set up archetypes.[1] He affirmed that all the more perfect organic beings, among which we include fishes, amphibians, birds, mammals (and at the head of the latter, man), were formed "according to an archetype, which merely fluctuates more or less in its very persistent parts, and moreover, day by day, completes and transforms itself by means of reproduction."

According to Goethe, "Nature always makes use of the same parts. Nature is inexhaustible in the modification and realisation of the archetype; but to that which has once attained realisation cleaves the tenacious power of persistency, a *vis centripeta*, of which the profound basis is beyond the influence of anything external. . . . The parts of the animal, their relative form, their conditions, their special characters, determine the requirements of the creature's existence."

Goethe is not quite clear as to the effect produced by environment and externalities upon the modifications of form. Thus in one place he speaks of persistency beyond the influence of anything external, while in another he leads us to infer that environment is equal to producing change of form and even creating organs. "Thus the eagle fashioned itself by the air for the air, by the mountain top for the mountain top. The mole fashions itself to the loose soil, the seal to the water, the bat to the air; . . . the animal is fashioned by circumstances to circumstances."

The doctrine that animals and their several parts are formed by environment and external conditions is one to which I cannot subscribe.

Cuvier showed that animals may be separated into several great divisions characterised by a peculiar constitution and by the arrangement and distribution of the organs. These divisions he designated "types" or "fundamental forms."

Richard Owen, who in 1830 had been Cuvier's pupil, and who devoted himself not only to comparative anatomy but also to palæontology, acquiesced in the archetype as giving him uniformity and stability amid multiplicity and diversity of detail. According to him the regular succession of parts and of organisms is "the result of natural laws and operating causes, which produce the species in regular sequence and gradual completion, such laws and causes being the servant of predetermining will."

He says: "I deem an innate tendency to deviate from the parental type, operating through periods of adequate duration, to be the most probable nature or way of operation of the secondary law, whereby species have been derived one from the other." He adds: "No one can enter the saddling-ground at Epsom before the start for the Derby, without feeling that the glossy-coated, proudly-stepping creatures led out before him are the most perfect and beautiful of quadrupeds. As such, I believe the horse to have been predestined and prepared for man."

Lamarck was the first to promulgate the doctrine of Descent, and in 1804 actually sketched out the theory so sedulously worked out by Mr. Charles Darwin. Lamarck's views have been epitomised by Professor Oscar Schmidt as under: "He proclaimed that it is merely our limited powers of comprehension that demand the erection of systems, whereas all systematic definitions and gradations are of artificial nature. We may be assured

[1] The idea of archetypes was not confined to Goethe. He, however, gave to them a prominent position by adding to them the idea of motion and mobility.

that nature has produced neither orders, families, genera, nor immutable species, but merely individuals which succeed one another, and resemble those from whom they descend."

Variations and transformations supervene, according to Lamarck, through external influences; in the lapse of ages they become essential differences; so that, after many successive generations, individuals which originally belonged to another species ultimately find themselves converted into a new one. The transformation is effected by the obligation of the individual to accommodate itself to the altered conditions of life. Fresh circumstances elicit fresh requirements and fresh activities. Great weight must be laid on the use or disuse of organs. In every animal still in the course of development, the more frequent and sustained use of an organ gradually fortifies, develops, and enlarges it, and endows it with strength proportional to the duration of this use; while the persistent disuse of an organ imperceptibly weakens and deteriorates it, diminishes its efficiency in an increasing ratio, and ultimately destroys it. And thus, he says, nature exhibits living beings merely as individuals succeeding one another in generations; species have only a relative stability, and are only transiently immutable.

According to the latter doctrine there is no First Cause and no Designer or design. Matter forms itself, assumes life, develops plants and animals, and lays down its own laws. Any interference with that development and with those laws is regarded as a miracle and an outrage upon nature.

While the three doctrines are more or less opposed as regards the beginnings of things, they derive their arguments from the present and past order of nature, that is, the proofs are to be found in existing plants and animals, and in pre-existing plants and animals as presented by palæontology in the geological record.

Those who believe in separate creations in time and space have no difficulty in accounting for the appearance, continuation, and disappearance of species and genera in different parts of the earth's surface. The breaking up of continents, the formation of islands, the submergence and emergence of land, the mighty upheavings caused by volcanoes, earthquakes, &c., do not disconcert them. Any breach in the continuity in the flora and fauna can be readily explained. It is otherwise with those who believe in spontaneous generation and a continuous evolution. With them the geological gaps are more or less insurmountable, and large assumptions have to be made, even to the supposed existence, at one period or other, of a southern continent.

In recent times some of those who believe in a Creator and design have modified their views to the extent that they regard creation as a continuous act, including first the gradual formation of matter; and second, the gradual formation of plants and animals from matter by the addition of life. There are others who refer the creation of the inorganic and organic kingdoms to isolated acts, and to two periods—the two kingdoms being endowed with illimitable potentialities and possibilities, whereby they develop according to law and order, and adapt themselves to every conceivable circumstance, but all under constant divine supervision.

The creationists naturally and necessarily believe in design, and in types and archetypes. Those who support the doctrine of spontaneous generation and evolution in the extreme sense reject design, and regard the division of plants and animals into species, genera, families, &c., as more or less arbitrary and consequently unwarranted.

There are only two things which the creationists and those who believe in spontaneous generation and evolution pure and simple have in common, and that is Descent and Heredity. Given life and the power of transmitting it, Descent and Heredity become a necessity. This follows because in all cases the offspring more or less closely resembles the parent or parents.

A question here emerges as to the amount of resemblance to the parent or parents, and the amount of difference and of variation. Is the difference such as in the fulness of time to constitute new beings, or is it confined within limits, and obliged to conform to certain types of plants and animals which figure in the great scheme of nature as original creations?

As already explained, Oken, Goethe, Cuvier, and Owen believed in types. To them may be added Linnæus, who dealt more especially with plants. The latter "attributed the individuals to a species, of which the pedigree ascended in a direct line to the pair which proceeded from the hands of the Creator."

Cuvier practically accepted the Linnæan definition of Species. "According to Cuvier the species is the aggregate of individuals descending from one another and from common ancestors, and of those who resemble them as strongly as they resemble one another. . . . Later the genealogical idea of the common descent of all individuals of each separate species was supplemented by the physiological definition that all the individuals of every species are capable of producing fertile offspring by intercrossing, whereas sexual intercourse between individuals of different species produces only sterile offspring or none at all." [1]

While stating, as in duty bound, the various conflicting views, I feel it incumbent upon me to express my

[1] The accuracy of the physiological definition has been disputed by Darwin and Haeckel. It is asserted that hares and rabbits—two well-known species—interbreed, as likewise dogs and wolves. Against this, provided it be admitted, is to be placed the fact that the mule and the hinny are invariably barren.

conviction that the preponderance of facts is greatly in favour of those who believe in creation and types, and in law, order, and design. I can see no room for spontaneous generation and blind chance in the great scheme of nature as represented by the inorganic and organic kingdoms.

THE FIRST APPEARANCE OF A NERVOUS SYSTEM; THE NERVOUS SYSTEM GENERALLY

It is very difficult, if not indeed impossible, in the present state of science, to say where a nervous system first appears in a tangible form. As our means of distinguishing textures by staining, dyeing, hardening, freezing, injecting, chemical re-agents, and high powers of the microscope increase, rudimentary nervous systems reveal themselves where they were not even suspected. Jelly-fishes, for example, were long believed to be destitute of a nervous system, and it is only of late years that one has been detected.

As already explained, there are good grounds for believing that the analogue of a nervous system exists in a semi-fluid diffuse form in plants and in the lowest animals, and that this gradually assumes consistence and shape when the organism becomes differentiated and its several parts require to be kept in touch.

That a nervous system, as we know it, is not necessary to movement, and to co-ordinated purpose-like movement, is proved beyond doubt by the movements in insectivorous plants, by the opening and closing rhythmic movements of the vacuoles in water plants, by the opening and closing movements of the heart of the chick, by the movements of plasmodium of *Badhamia utricularis*, the amœba, white blood-corpuscles, *gromia*, &c.

So far as known at present the medusa, on the whole, supplies the most rudimentary nervous system. It is consequently entitled to much consideration.

The medusa, otherwise called the jelly-fish, from its exceedingly soft, jelly-like consistence, is very simple and symmetrical as to its several parts. It consists of a mushroom or umbrella-shaped disc with a central portion, called the manubrium or handle, from its resemblance to the stalk of a mushroom or the handle of an umbrella. It forms one of a numerous family, and ranges from the size of a small, rounded, brass-headed tack, to that of a saucer, a wash-hand basin, a parasol, or even an umbrella. In the largest specimens the pendants or streamers sometimes measure 100 or more feet in length. The disc or umbrella of the medusa is divided into two parts; an upper, very thick, jelly-looking, non-contractile part, and a lower, exceedingly thin, contractile part, which somewhat resembles rudimentary muscular fibre in structure. The lower contractile part of the disc provides the organ of locomotion. The manubrium consists of the head, stomach, and organs of generation; the latter appearing as pendants or streamers. The manubrium also consists of a non-contractile and contractile part. An intimate connection subsists between the disc and the manubrium and parts thereof. Thus where the manubrium is joined to, and suspended from, the disc, it sends out a radiating system of tubes or canals which permeate the nether, thin, contractile layer, and communicate with and terminate in a peripheral or circular tube or canal. This peripheral or circular canal communicates by minute apertures with the water in which the medusa is immersed. These radiating tubes, which extend between the mouth and the circular peripheral canal, perform an alimentary function, and are of two kinds. In some cases they radiate in straight lines, and do not bifurcate or branch as they near the peripheral or circular canal: in other cases they bifurcate or branch freely in their course. This, with other anatomical differences to be noted presently, has been taken advantage of to divide the medusæ into two great classes; those with radiating straight tubes being called "naked-eyed," those with radiating bifurcating tubes being known as "covered-eyed." The margin of the disc in the naked and covered-eyed medusæ displays a series of contractile tentacles which vary in number and size in different species. It also contains the so-called "marginal bodies," which also vary in number, size, and structure. The marginal bodies in the covered-eyed medusæ occur as "lithocysts" or little bags of crystals, the bags being composed of gelatinous tissue; hence the epithet covered-eyed, as distinguished from the naked-eyed, where the little bags are always, and the crystals are not unfrequently, absent.

A large area of the body of the medusa is devoted to the purposes of locomotion. The medusa advances or swims by the alternate opening and closing of the under contractile part of its umbrella-like disc. The under contractile part of the disc opens slowly and closes somewhat suddenly, both movements being vital in their nature. When the under part of the disc closes it compresses and acts upon a fluid wedge of water; the animal of necessity gliding forward. The opening and closing movements are centrifugal, centripetal, and rhythmic in character. The rapidity of the rhythms varies according to the vigour of the individuals, the time of day, the degree of heat, &c. Usually they are about twenty to the minute.

The manubrium and streamers, like the disc, are composed of gelatiniform masses, varying in consistency; some portions being more solid than others. Thus there are usually four fairly solid masses in the centre of the animal, which afford support for the manubrium, and a *point d'appui* for the opening and closing movements of the disc. They also provide attachments for the organs of reproduction and the streaming appendages.

From the foregoing it will be seen that while the medusa, generally speaking, consists of a soft, jelly-looking mass, it is nevertheless differentiated to a considerable extent. This is proved by the gelatiniform mass forming its body varying in consistence, by the disc and manubrium being provided with non-contractile and contractile substances, by its being furnished with a stomach and system of radiating water tubes or channels (straight or branched), by its possessing rudimentary sense organs, generative apparatus, marginal bodies, lithocysts, &c.

The differentiation referred to naturally pointed to the existence of a nervous system, and accordingly many distinguished zoologists undertook researches for its discovery. These researches extended over several years. The following among others have contributed to the elucidation of this important and interesting subject: Ehrenberg (1836), Kölliker and Von Beneden (1843), Krohn (1851), McCrady and Fritz Müller (1859), L. Agassiz (1860), Hensen (1863), Claus (1864), Haeckel (1865), Allman (1867), Leuckhart (1872), Eimer (1874), Romanes (1885).

Mr. Romanes, who worked enthusiastically at the subject, by experiment and otherwise, has epitomised the researches of Haeckel and Eimer as follows: [1]—

"Professor Haeckel, who made his microscopical observations chiefly upon the Geryonidæ, described the nervous elements as forming a continuous circle all round the margin of the umbrella, following the course of the radial or nutrient tubes throughout their entire length, and proceeding also to the tentacles and marginal bodies. At the base of each tentacle there is a ganglionic swelling, and it is from these ganglionic swellings that the nerves just mentioned take their origin. The most conspicuous of these nerves are those that proceed to the radial canals and marginal bodies, while the least conspicuous are those that proceed to the tentacles. Cells, as a rule, can only be observed in the ganglionic swellings, where they appear as fusiform and distinctly nucleated bodies of great transparency and high refractive power. On the other hand, the nerves that emanate from the ganglia are composed of a delicate and transparent tissue, in which no cellular elements can be distinguished, but which is longitudinally striated in a manner very suggestive of fibrillation. Treatment with acetic acid, however, brings out distinct nuclei in the case of the nerves that are situated in the marginal vesicles, while in those that accompany the radial canals ganglion cells are sometimes met with.

"A brief sketch of the contents of these and other memoirs on the histology of the medusæ is given by Drs. Hertwig in their more recently published work on the nervous system and sense organs of the medusæ, and these authors point to the important fact that before the appearance of Haeckel's memoir, Leuckhart was the only observer who spoke for the fibrillar character of the so-called marginal ring-nerve; so that in Haeckel's researches on Geryonia, whereby both true ganglion cells and true nerve fibres were first demonstrated as occurring in the medusæ, we have a most important step in the histology of these animals. Haeckel's results in these respects have since been confirmed by Claus and others."

Romanes has likewise epitomised the important work done by Drs. O. and R. Hertwig on the nervous systems of the naked and covered-eyed medusæ respectively: "Beginning with the naked-eyed division, they describe the nervous system as consisting of two parts, a central and a peripheral. The central part is localised in the margin of the swimming-bell, and there forms a 'nerve ring,' which is divided by the insertion of the 'veil' into an upper and a lower nerve ring. In many respects the upper nerve ring is spread out in the form of a fattish layer, which is somewhat thickened where it is in contact with the veil. In these species the nerve ring is only indistinctly marked off from the surrounding tissues. But in other species the crowding together of the nerve-fibres at the insertion of the veil gives rise to a considerable concentration of nervous structures; while in others, again, this concentration proceeds to the extent of causing a well-defined swelling of nervous tissue against the epithelium of the veil and umbrella. In the Geryonidæ this swelling is still further strengthened by a peculiar modification of the other tissues in the neighbourhood, which had been previously described by Professor Haeckel. In all species the upper nerve ring lies entirely in the ectoderm. Its principal mass is composed of nerve fibres of wonderful tenuity, among which are to be found sparsely scattered ganglion cells. The latter are for the most part bi-polar, more seldom multi-polar. The fibres which emanate from them are very delicate, and, becoming mixed with others, do not admit of being further traced. Where the nervous tissue meets the enveloping epithelium it is connected with the latter from within, but differs widely from it; for the nerve cells contain a longitudinally striated cylindrical or thread-like nucleus which carries on its peripheral end a delicate hair, while its central end is prolonged into a fine nerve fibre. There are, besides these, two other kinds of cells which form a transition

[1] "Primitive Nervous Systems of the Jelly-fish, Star-fish, and Sea-urchins," by G. J. Romanes, M.A., LL.D., F.R.S. London, 1885.

between the ganglion and the epithelium cells. The first kind are of a long and cylindrical form, the free ends of which reach as far as the upper surface of the epithelium.

"The second kind lie for the most part under the upper surface. They are of a large size, and present, coursing towards the upper surface, a long continuation, which at its free extremity supports a hair. In some cases this continuation is smaller, and stops short before reaching the outer surface. Drs. Hertwig observe that in these peculiar cells we have tissue elements which become more and more like the ordinary ganglion cells of the nerve ring the more that their long continuation towards the surface epithelium is shortened or lost, and these authors are thus led to conclude that the upper nerve ring was originally constituted only by such prolongations of the epithelium cells, and that afterwards these prolongations gradually disappeared, leaving only their remnants to develop into the ordinary ganglion cells already described.

"Beneath the upper nerve ring lies the lower nerve ring. It is inserted between the muscle tissue of the veil and umbrella, in the midst of a broad strand wherein muscle fibres are entirely absent. It here constitutes a thin though broad layer, which, like the upper nerve ring, belongs to the ectoderm. It also consists of the same elements as the upper nerve ring, namely, of nerve fibres and ganglion cells. Yet there is so distinct a difference of character between the elements composing the two nerve rings, that even in an isolated portion it is easy to tell from which ring the portion has been taken. That is to say, in the lower nerve ring there are numerous nerve fibres of considerable thickness, which contrast in a striking manner with the almost immeasurably slender fibres of the upper nerve ring. A second point of difference consists in the surprising wealth of ganglion cells in the one ring as compared with the other. Thus, on the whole, there is no doubt that the lower nerve ring presents a higher grade of structure than does the upper, as shown not only by the greater multiplicity of nerve cells and fibres, but also by the relation in which these elements stand to the epithelium. For in the case of the lower nerve ring, the presumably primitive connections of the nervous elements with the epithelium is well-nigh dissolved—this nerve ring having thus separated itself from its parent structure, and formed for itself an independent layer beneath the epithelium. The two nerve rings are separated from one another by a very thin membrane, which, in some species at all events, is bored through by strands of nerve fibres which serve to connect the two nerve rings with one another.

"The peripheral nervous system is also situated in the ectoderm, and springs from the central nervous system, not by any observable nerve trunks, but directly as a nervous plexus composed both of cells and fibres. Such a nervous plexus admits of being detected in the sub-umbrella of all medusæ, and in some species may be traced also into the tentacles. It invariably lies between the layer of muscle fibre and that of the epithelium. The processes of neighbouring ganglion cells in the plexus either coalesce or dwindle in their course to small fibres: at the margin of the umbrella these unite themselves with the elements of the nerve rings. There are also described several peculiar tissue elements, such as, in the umbrella, nerve fibres which probably stand in connection with epithelium cells; nerve cells which pass into muscle fibres, similar to those which Kleinenberg has called neuro-muscular cells; and, in the tentacles, neuro-muscular cells joined with cells of special sensation (*Sinneszellen*).

"No nervous elements could be detected in the convex surface of the umbrella, and it is doubtful whether they occur in the veil.

"In some species the nerve fibres become aggregated in the region of the generative organs, and in that of the radial canals, thus giving rise in these localities to what may be called nerve trunks. But in other species no such aggregations are apparent, the nervous plexus spreading out in the form of an even trellis-work.

"In the covered-eyed medusæ the central nervous system consists of a series of separate centres which are not connected by any commissures. These nerve centres are situated in the margin of the umbrella, and are generally eight in number, more rarely twelve, and in some species sixteen. They are thickenings of the ectoderm, which either encloses the bases of the sense organs, or only covers the ventral side of the same. Histologically they consist of cells of special sensation, together with a thick layer of slender nerve fibres. Ganglion cells, however, are absent, so that the nerve fibres are merely processes of epithelium cells.

"Drs. Hertwig made no observations on the peripheral nervous system of the covered-eyed medusæ; but they do not doubt that such a system would admit of being demonstrated, and in this connection they cite the observations of Claus, who describes numerous ganglion cells as occurring in the sub-umbrella of Chrysaora." [1]

Drs. Hertwig "compare the nervous system of the naked-eyed with that of the covered-eyed medusæ, with the view of indicating the points which show the latter to be less developed than the former. These points are,

[1] Professor Schäfer, prior to the publication of the works by Drs. Hertwig, "succeeded in showing an intricate plexus of cells and fibres overspreading the sub-umbrella tissue of another covered-eyed medusa (*Aurelia aurita*). He also found that the marginal bodies present a peculiar modification of epithelium tissue, which is on its way, so to speak, towards becoming fully differentiated into ganglionic-cells" (*Phil. Trans.*, pt. ii., 1878).

that in the nerve centres of the covered-eyed medusæ there are no true ganglion cells, or only very few; that the mass of the central nervous system is very small; and that the centralisation of the nervous system is less complete in the one group than in the other. In their memoir these authors further supply much interesting information touching the structure of the sense organs in various species of medusæ."

There are several points in the nervous system of the medusæ which are worthy of serious consideration, such as (*a*) its rudimentary character; (*b*) its transitional condition; (*c*) its connection with epithelium cells; (*d*) its connection with imperfect muscular fibres and muscles; (*e*) its central and peripheral nature; (*f*) its being composed of widespread, uniform, very delicate, transparent nerve plexuses, with an admixture in certain cases and in certain localities of well-defined nerve fibres; (*g*) its possession of nerve cells and ganglia—these being for the most part bipolar and multipolar.

Here, so to speak, is the birth and development of the first tangible nervous system. Though simple to a degree, the elements of even the most complex nervous systems are present in a rudimentary form. The nervous system of the medusa evidently forms the connecting link between the lowest animals and plants where there is no nervous system, and between the highest animals and man where there is a highly elaborated nervous system. Its very delicate, semi-transparent, uniform, widespread nerve plexuses make a transition from it to a non-visible, semi-fluid, diffuse nervous system as it probably exists in plants and the lowest animals easy, while its possession of a central and peripheral set of nerves with bipolar and multipolar nerve cells and ganglia with their concomitant nerve fibres and trunks (afferent and efferent), to which are to be added rudimentary special sense nerves, identify it more or less completely with the visible, outstanding nervous systems of the higher animals, up to and including man.

The nervous system of the medusa provides a means of communication between the several parts of its body and between its body as a whole and the outer world, as represented by water, light, heat, food, &c. It furnishes a machinery which enables it to inaugurate and control its movements, to work and rest, to appropriate and assimilate food, to eject waste products, &c.

The nerves and muscles of the medusa, as explained, exhibit centripetal and centrifugal movements, and these movements occur in waves, and are rhythmic in character. They take place in the molecules of the nerve cells, ganglia, and nerve fibres; in the muscles they occur in the sarcous elements, and are witnessed in the so-called muscular contractions and relaxations. The nerve cells, and ganglia provided with nerve fibres, exercise a triple power. They generate nerve force, receive messages from without, and transmit messages from within. They perform the rôle of rudimentary brains. When an animal, however low in the scale of being, is provided with a nervous system consisting of nerve cells, ganglia, and nerve fibres, it becomes a sensitive voluntary agent. It is provided with a machinery which ensures a low form of cognition. It can move to definite ends, and is in no sense an automaton goaded into activity by external stimuli.

The object of a nervous system in all cases is to connect the individual with the physical universe, and to concentrate and bring its several parts together under a central control. Where there is differentiation of tissues, of organs, and functions, a nervous system becomes a necessity. Differentiation implies division of labour, and such labour is unproductive unless co-ordinated. The co-ordinating element in every instance is the nervous system. Differentiation and division of labour come into play in building up, maintaining, and carrying on the every-day life of the higher organisms.

The movements of the medusæ cannot, strictly speaking, be regarded as reflex movements. The medusa has no spinal cord or brain proper, but its movements are nevertheless voluntary. A brain is not necessary to voluntary movements in many of the lower animals. The possession of nerve cells, nerve ganglia, and nerve fibres enables them to dispense with the crowning structure of the nervous system as we know it.

In the higher animals a brain makes its appearance, but the brain is, in every instance, composed of a congeries of nerve cells, ganglia, and nerve fibres similar, for the most part, to those found in the medusæ and the lower animals. If, however, there is similarity of structure in the nervous system of the lower and higher animals, it goes without saying that all nerve manifestations, the intellectual included, differ not in kind but only in degree. This circumstance makes it next to impossible to distinguish between sensation, feeling, perception, volition, judgment, memory, and even consciousness, in the lower and higher animals. It has been attempted, but with no great measure of success, to draw a line of demarcation between the brain of man and that of the lower animals, reserving for man all the higher attributes of the mind, and denying to the lower animals reason and consciousness even in their most rudimentary form. It has further been attempted to explain a large number of the movements of the lower animals by reflex acts, and to deny them the power of volition. All such attempts at limiting the powers of the nervous system must, from the nature of the case, fail. In animals provided with a nervous system (minus a brain) it is reasonable to infer that they are given the power of regulating their movements and

lives, that this power is increased when a rudimentary brain makes its appearance, and that the intellectual powers are added to in proportion as the brain becomes larger in volume, more complex in structure, and finer in quality.

It is a mistake to infer, because in man the nervous system consists of a highly organised brain with nerve cells, ganglia, and nerve fibres, and of a spinal cord similarly constituted, that the brain and spinal cord are separate, and act as two different nervous systems; the former being the centre of volition, judgment, consciousness, memory, &c., the latter being the centre only of involuntary, reflex acts, such as are said to regulate the actions of the lower animals.

In paraplegia in man, the brain and upper half of the body are functionally separated from the spinal cord and lower half of the body by disease. In such a case, by tickling the soles of the feet the limbs may be made to move involuntarily by so-called reflex acts; the individual being unconscious both of the tickling and of the movements so induced. It should, however, be remembered that these so-called reflex acts are primarily the result of voluntary training, and of habit induced by frequent repetition when the cerebro-spinal nervous system was intact, and before it was invaded by disease. In a healthy individual the movements produced by the tickling are largely voluntary in character. Moreover, the abnormal condition known as paraplegia does not necessarily prove that in the lower animals devoid of brains, and with only nervous systems composed of nerve cells, ganglia, and nerve fibres, their actions are involuntary or reflex, and performed unconsciously. The brainless nervous systems of the lower animals are doubtless equal to their work, and the fact that the said animals act deliberately, purposely, and to given ends, forbids the assumption that brains, in the higher sense, are indispensable. The brain is a mere accretion of nerve cells, ganglia, and nerve fibres, and when it is absent and the elements composing it are present we are not entitled to limit the action of the nervous system; on the contrary, we are bound to assume that the elements contain, in an incipient form, many, if not all, the powers which centre in the brain itself. The ganglia in the brainless nervous systems of the lower animals perform, as has been already explained, in many cases, the rôle of brains in the more elaborate nervous systems of the higher animals.

All the lower animals which are possessed of brains exercise, within limits, the functions performed by the brain of the higher animals and of man, and no one can say that even the lowest animals which have a nervous system but no brains are incapable of regulating their movements, or that their movements are involuntary and the result of reflex acts.

The fact that voluntary and involuntary movements occur in man and in the higher animals does not prove that the movements of the lower and lowest animals are involuntary or reflex.

There are several ways of studying the nervous system.

(*a*) In its beginnings as seen in the medusa.

(*b*) In embryology and development as witnessed in the highest animals.

(*c*) In disease and injury by accident.

(*d*) By the aid of comparative anatomy, and by studying the nervous system from below upwards.

(*e*) By a comparison of the nervous system and intellect as between the aborigines and the cultivated races, Europeans for example.

(*f*) By microscopic examination of the nervous system of dead animals as aided by staining, chemical reagents, &c.

(*g*) By means of vivisection or experiments on living animals.

The last method (vivisection) is that most in vogue, but in every respect it is the least reliable and satisfactory. This follows, because when nerves are divided and an animal is hacked with scalpels, scissors, &c., in various directions, the results are never perfectly normal. The same is to be said of artificial stimulation of the nervous system and of the muscular system by means of electricity, galvanism, cautery, pricking, &c. Living sensitive structures cannot be expected to respond kindly or naturally to such severe, crude methods.

Mr. Romanes planned and carried out an extensive series of vivisection experiments on the nervous system of the medusa with a view to ascertaining the value of that system from the physiological side. He, however, resorted to such extensive mutilations as to render his experiments in a great measure nugatory. Thus, in some cases, he cut out the manubrium or central part of the medusa before proceeding to experiment on its disc or umbrella. In other cases he cut out the manubrium and in addition concentric rings of the disc before experimenting on the peripheral portion of the disc. In a third series he cut the disc or umbrella into a long, continuous, spiral ribbon. In a fourth he notched the concentric rings and spiral ribbons of the disc so deeply that they were all but detached from each other. He also applied electricity and various forms of artificial stimuli to the mutilated portions of the medusa.

It is not conceivable that normal results could be obtained from an animal so abnormally treated, and this

appears from the contradictory results ever and anon produced. Moreover, allowing the results to have been uniform, it does not follow that they were natural or normal results.

The remarks made upon the vivisection nerve experiments of Mr. Romanes apply to all similar experiments on the higher animals, with this difference, that they become less reliable as the nervous system becomes more elaborate and the animals more highly organised, more sensitive, and more subject to shock.

One has only to study the movements of the medusa in its native element to be convinced that they are voluntary and under control, and that they are in no sense reflex, or the result of irritation or external stimulation. The medusa is a living thing placed in a congenial environment, and it lives and moves in virtue of inherent endowments conferred upon it at its birth. Its movements and powers are doubtless of a low type, but they are sufficient for its purpose. The medusa is in no sense an automaton spurred into activity by its natural surroundings—the water, heat, light, &c. The movements of the medusa come from within and not from without. A careful analysis and study of the swimming of the jelly-fish, by myself, with drawings, is given at sections 360 to 365. The action of the medusa in swimming is not unlike the action of the diaphragm in the higher animals in breathing. The movements of the disc of the medusa in reality prefigure those of the hollow viscera (heart, stomach, bladder, uterus, &c.) as a class. They also prefigure those of the voluntary muscular system as a whole. It is interesting to note that the muscular and nervous systems of the medusa are diffuse in the sense that they extend over a large area of the animal. The movements of the medusa are diffuse in the same sense. Thus the organ of locomotion includes the whole of the thin, nether, contractile disc. It is a curious circumstance that in proportion as development and differentiation proceed, and the nervous system increases in complexity, the parts of the body employed in locomotion diminish in number and extent. Thus in the star-fish and echinus, especially the latter, there are numberless small tube-feet or pedicles which are capable of being protruded or retracted. In the centipede the number of feet is reduced, but still large. In the insect they are still further reduced.

In the fish the fins and tail, especially the latter, perform the offices of locomotion; in the crocodile there are four feet and a huge swimming tail; in the quadrupeds, four small feet; in the biped, two feet and two hands; in the bird, two feet and two wings. The extent or surface of the travelling organs is least in land animals, greatest in aerial animals, and intermediate in aquatic animals. The travelling surfaces, in addition, bear a relation to the medium to be traversed. All these contrivances and arrangements are means to ends, and afford arguments in favour of design.

As it would be a well-nigh endless task to trace the development of the nervous system from the medusa up to man, I propose to deal only with typical and representative examples as they occur in the star-fish, the aplysia, the centipede, the vertebrata, and in man.

In the five-rayed star-fish the nervous system is more pronounced than in the medusa (see Plate cxxxi., Fig. 2, A, p. 749).

§ 218. The Nature and Peculiarities of the Nervous System.

The nervous system, whether simple or complex, is, like other living systems, composed of organic matter, capable of moving in its ultimate particles. It is endowed with a centripetal and a centrifugal power, and its molecular and other movements and manifestations are directed towards groups of nerve cells, ganglia, neurons, &c.; or, conversely, away from them, in the direction of the skin, organs of various kinds, and muscles when present. The nervous system, as regards its molecules, is in a continuous state of flux between the skin or outside covering of the body on the one hand, and the several organs and systems which constitute the individual, on the other. There is an ebb and flow, a pulsation of nerve force from the outer and inner portions of living bodies, which is unceasing even in sleep. In sleep the function of the nervous system, like that of every other system of the body, is lowered. This follows because the nervous system, like all other systems, must rest and be nourished; the rest and nourishment taking place in different parts at different times, so as not to interfere with the continuity of function and life in the creature as a whole.

The nervous system is sentient in a double sense; it feels the outer world wherever and whenever it comes in contact with it; it also feels its several parts, and itself, and is conscious. This power of feeling and of knowing what is external and internal, and of distinguishing between what is good and bad as far as nourishment and other things connected with the well-being of the individual are concerned, extends low down in the scale of being. It were not otherwise possible for the lower and lowest animals to maintain their places in nature. Similar powers may be claimed for plants where, so far as known, no nervous system exists. A diffuse nervous system in plants is by no means impossible; indeed its existence is rendered highly probable by the movements of sensitive, insectivorous, and other plants. The movements of plants, and the lowest animals, unequivocally

point to a discerning and controlling power which regulates and determines their movements. A careful and minute study of the movements and economy of the sundew, the amœba, gromia, and many low animal forms makes this all but certain. As time advances it becomes more and more evident that living things, plant and animal, have very much in common both as regards the materials entering into their composition and their springs of action. If plants and the lowest animals have no muscular and no nervous systems, they have, nevertheless, in their substance the homologues and representatives of both. Muscles and nerves have no advantage over other structures expressly formed to perform certain functions. All that can be said is that muscle represents the highest form of moving organic matter, and nerve the most exalted, controlling, and directive living force. Like results can evidently be obtained from dissimilar materials.

The nervous system acts in two principal directions and with equal facility. This is necessary to receive impressions from without, and to send impulses or commands from within. Each territory, in a compound animal, is under its own nerve centres, but all the territories and nerve centres are under the brain, directly or indirectly, when that exists. The nerve centres can, nevertheless, act spontaneously and apart from the brain. While the movements of the molecules of the sensory and motor nerves are centripetal and centrifugal in character, and the movements of the molecules of the nerve centres largely so, the latter are endowed with independent movements—movements connected with the interpretation of sensations, with the formation of volitions, &c.

The so-called reflex movements, if the nerve centres which regulate them only be considered, are as direct as the voluntary movements. The brain has no advantage over the nerve centres in the spinal cord and in the sympathetic system, unless in its greater bulk, capacity, and power. As a matter of fact, the brain is a development, extension, and differentiation of the spinal cord.

The arrangement of the sensory and motor nerves found in the cord is repeated and amplified in the brain, with the difference that such of the sensitive nerves of the brain as are confined within the bony cranium are modified and dwarfed because of disuse. The intervention of the thick, hard skull prevents their free extremities coming in contact directly with the outer world as in other parts of the body, a circumstance which dulls their sensibility and in great measure accounts for the comparative insensitiveness of the greater part of the brain. This is a new point, and is elaborated further on. The sensory nerves of the brain which escape from the bony skull and reach the surface of the head are amongst the most sensitive in the body; they are largely the nerves of sense—the gustatory, olfactory, auditory, optic, &c.

The groups of nerve cells, ganglia, and neurons in the brain and spinal cord, with their concomitant afferent and efferent nerves, preside, as indicated, over certain territories separately or in combination; the brain being merely the head or chief centre. In this sense collections of nerve cells, ganglia, &c., are to be regarded as little or particular brains (brainlets), in contradistinction to the general or great brain.

Nerve cells and ganglia feel and are conscious, in a way, whenever and wherever they occur in quantity. A brain is not necessary to feeling and knowing. These functions may be performed by the spinal cord as apart from the head. Thus if a probe be placed in the cloaca of a frog, just decapitated, it attempts to extract it. Similarly, if mustard be put on one of the thighs of a headless, living frog, it deliberately scrapes it off by the aid of the foot of the opposite limb. These movements cannot be classed under ordinary reflex, purposeless acts. They display intention, and are, within limits, voluntary.

The nerve cells and ganglia of the cord, when active, feel through the sensitive nerves even to their extremities. They also send out impulses by the motor nerves to the muscles and the various other organs and substances in which they terminate. A distinction is to be drawn between nerve cells, ganglia, sensory and motor nerves, in a state of activity and in a state of repose. The feeling and conscious condition of nerve substance is, strictly speaking, the active condition. One is not conscious during sleep, and impacts made on the skin, and sensations, in the somnolent state, are not perceived.

The view here given of the living, active, sensory, and motor nerves differs from that in vogue at the present day. According to prevailing opinions the sensory and motor nerves are mere mechanical vehicles of transmission. They are to the nerve centres what a copper or other wire is to an electric battery. There is, however, this important distinction; the sensory nerve is living and sentient, and the motor nerve is living and motor. In the active state the transmission of sensory and motor impulses is comparatively very rapid, much more so than would be the case if the impulses acted as dead substances. If one place his finger on a piece of ice he feels the cold instantly. The act and the perception of cold are, to all intents and purposes, simultaneous. If he wills to raise his hand, the volition and the elevation are practically synchronous. These results are obtained when the experimenter fixes his attention on the work in hand. I am well aware that an infinitesimal amount of time must elapse in the transmission of nerve energy, and that the time can be measured. My contention is that the time consumed is much less than it would be if the sensory and motor nerves were non-living structures.

If the nervous system be regarded as a congeries of nerve cells, ganglia, neurons, &c., with afferent and efferent nerves extending to all parts of the body; and if, further, it be regarded as a living, sentient, moving system, capable of receiving external impressions, generating volitions, and sending out motor impulses; it is not difficult to understand how every part of even comparatively simple animals is under control.

A very rudimentary nervous system suffices for the needs of the jelly-fish, which is a simple animal; a very complex one is required for man, the most exalted of the animal series.

That groups of nerve cells, ganglia, neurons, &c., have the power of receiving and interpreting messages from without, and of sending out motor impulses from within, is proved by the spontaneous, co-ordinated, purpose-like movements of animals having nervous systems, but no brains in the ordinary sense. It is also proved in the case of decapitated animals with brains where the nerve centres in the spinal column exercise the brain functions.

That all the functions discharged by the brain, even in the highest animals (man included), are traceable to molecular stability and changes occurring in the nerve centres and other parts of the brain is apparent from this, that if the molecular balance of the brain be disturbed by a sudden knock on the head, as in concussion, or by disease, as in brain softening, all the intellectual faculties, even consciousness, disappear.

While the nerve centres can undoubtedly be acted upon from without, they also possess the power of acting spontaneously from within. They are capable of generating and sending out impulses which are virtually volitions. The more highly differentiated nerve centres in the brains of the higher animals can, and do, act apart from any form of irritation or stimulation. Even a motive is not necessary to brain action. The power of thinking, as well as of feeling and knowing, inheres in the molecules of the brain substance, and no thought, or chain of thought, can occur as apart from molecular brain changes. Time was when the brain was considered the organ of the mind, as the instrument was considered the organ of the musician. A duality was claimed. The mind was regarded as something apart from, and superior to, the brain, just as the musician was regarded as something apart from, and superior to, the instrument he played. The mind, in short, was said to be immaterial. It is now admitted on all hands, that intellect, in all its varieties, is as much the product of the brain as digestion is the product of the stomach. This doctrine was first promulgated by Sir William Lawrence, the distinguished surgeon and original observer, in his eloquent lectures delivered as far back as 1822.[1] Arguments in support of the material nature of mind are given elsewhere in this work, and it may suffice if I say, in a word, that intellect (the power of feeling, knowing, willing, judging, remembering, &c.) increases in proportion to the size and quality of the brain, alike in the lower animals and the several races of mankind. There is, in every case, a direct relation between the volume and quality of the brain and the intellectual powers.

The nervous system always appears in connection with contractile, moving substances, especially muscles. Muscle and nerve are indispensable to each other. They are, in the strictest sense, complementary structures. A nervous system without a muscular system would be futile to a degree. Each would be incomplete of itself. The muscles carry out the behests of the will in the higher animals, and what represents will in the lower animals devoid of brain. The nervous and muscular systems react upon and develop each other. The power of generating movements resides in nerve and muscle alike. Both nerves and muscles are capable of moving spontaneously. While, as a rule, they move together and act in concert, they can, if need be, act separately and independently. Thus one may reflect or meditate, and yet be perfectly quiescent as far as muscular movements are concerned; the heart, on the other hand, will continue to beat when severed from its nervous connections, and when deprived of the nerve ganglia situated on its surface and in its substance. For the wisest of purposes the nervous and muscular systems are only partly under control. These systems, in the higher animals, are necessary to carry on the fundamental functions of life (alimentation, respiration, the circulation, &c.), in addition to, and apart from, voluntary movements dependent on volitions.

The movements of plants and the lowest animals are not due to a nervous system as we know it. The lowest animals and plants move, and move freely and to given ends, where no trace of a nervous system can be detected.

While the nervous system does not, as a rule, confer motion on the involuntary muscles, the nerves in many cases exert a controlling and regulating influence. This is seen in the vaso-motor and respiratory nerves, the former regulating the flow of blood, the latter the respiratory movements. The voluntary muscles are more amenable to nerve influences.

The higher and lower animals possessed of a nervous system are to be regarded as a whole. They are living, sentient, spontaneously moving creatures. They feel as a whole, and move as a whole, or as parts of a whole. This is especially true of the so-called rhythmic movements occurring in the chest, heart, alimentary canal, bladder, uterus, &c.

Questions have arisen from time to time (*a*) as to whether the nervous system inaugurates the movements

[1] "Lectures on Physiology, Zoology, and the Natural History of Man." London, 1822.

of muscles and other structures, and (*b*) as to whether the nervous system acts rhythmically. There can, I think, be little doubt that muscles can, and do, act rhythmically independently of nerves, although usually muscles are more or less under nerve control. It seems equally certain that the nerves, and nerve centres, act rhythmically whenever and wherever they are connected with structures which exhibit rhythmic movements. If this were not so, the muscular and nervous systems, instead of being complementary, might be antagonistic.

The nervous system, like the muscular one, is, for the most part, symmetrical. This is well seen in the nervous arrangements of the five-rayed star-fish, the centipede, and the spinal cord and brains of vertebrates.

While each half of the nervous system as witnessed in the spinal cord and brains of the higher vertebrates is complete in itself, there is, nevertheless, structural continuity and functional communication between the two halves by means of commissural nerve fibres which run in a transverse direction and have a crossed action. The transverse nerve fibres extend throughout the entire length of the cord; they also occur in the medulla oblongata, the cerebellum, and cerebrum. The transverse or cross nerve fibres are necessary to ensure uniformity of action between the several parts of the spinal cord, medulla oblongata, cerebellum, and cerebrum, respectively. The several parts of the brain and spinal cord are united to each other by longitudinal and oblique nerve fibres in addition to the transverse ones; an arrangement which further increases the structural continuity and uniformity of function of both brain and cord.

The crossed action of the brain and cord is illustrated by experiment and disease. When there is injury or disease of one half, or part of one half, of the brain, there is, generally, paralysis of the opposite half of the nervous system. This paralysis may affect the right or left side of the body (*hemiplegia*), according as the left or right side of the brain is diseased or injured. If the injury be more central it may produce paralysis of both sides of the body (*general paralysis*), or only the lower half of the body (*paraplegia*).

While the great majority of animals are symmetrical as regards their nervous and muscular systems, there are, occasionally, asymmetric animals, of which Aplysia, one of the molluscs, furnishes a good example. In the higher animals, and in ourselves, by much the larger portion of the body is symmetrical, as witness the cerebro-spinal nervous system, the voluntary and involuntary muscular systems, the respiratory, circulatory, lymphatic, and osseous systems, &c. The asymmetric portions of the body are met with in part of the sympathetic system of nerves, in the liver and certain glands, and in the general arrangement of the intestines.

On the whole the safest and best approach to the nervous system is through the lower animals, such as the jelly-fish, star-fish, centipede, fish, reptile, and bird; the system culminating in mammals, especially in man. By tracing the nervous system from below upwards, all the links of a great, complicated, and curiously interwoven chain may be accounted for. It will also be found that the muscular system is developed *pari passu* and keeps pace with the nervous system, clearly showing that the two great systems are best considered together. Wherever we meet with a rudimentary nervous system, there too we encounter an imperfect muscular system. The two advance, as it were, hand in hand.

The several parts of the nervous system in the lower animals and in man are illustrated at Plates cxxvii. to cxlii., and should be carefully studied and compared.

The nervous system is fundamentally composed of protoplasm. In the higher animals the following differentiations are to be noted :—

1. An infinity of molecules, cells, and ganglia.
2. A large number of blood-vessels, and an unusual and plentiful supply of blood.
3. A full complement of lymphatics.
4. Blood sinuses for regulating and preventing undue blood pressure.
5. A rich vaso-motor system connected with the distribution of blood in the cranium.
6. Serous and other fluids which assist in maintaining the requisite fluidity of the surface and substance of the brain.
7. A plethora of nerve elements arranged in free ends, loops, plexuses, &c.

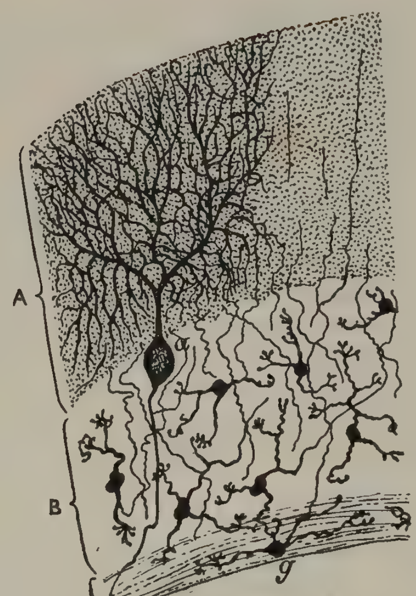
If attention be confined to the distribution of the nerve substance alone, the following parts can be made out :—

(*a*) Nerve cells in various degrees of perfection. They are usually connected with poles or nerve endings, and may be unipolar, bipolar, or multipolar. In the latter case they are generally called ganglia.

(*b*) The nerve cells, in many instances, form nerve plexuses which are found on the surface and in the substance of the body.

The nerves of transmission have been primarily divided into sensory and motor; the former conveying sensory impressions from the skin to the spinal cord and brain. These run *from without inwards*, and connect the individual with the external world. The latter convey impressions or motor impulses *from the spinal cord or brain* (when these are present) *to the muscles*.

PLATE CXXVII



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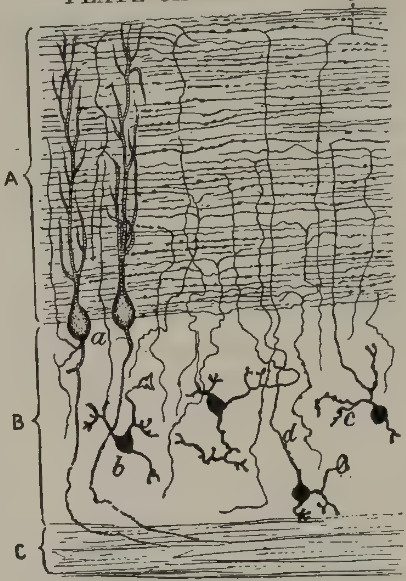

Fig. 7.

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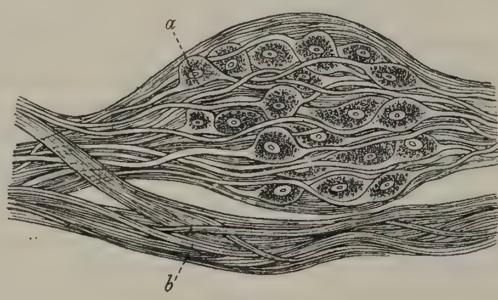

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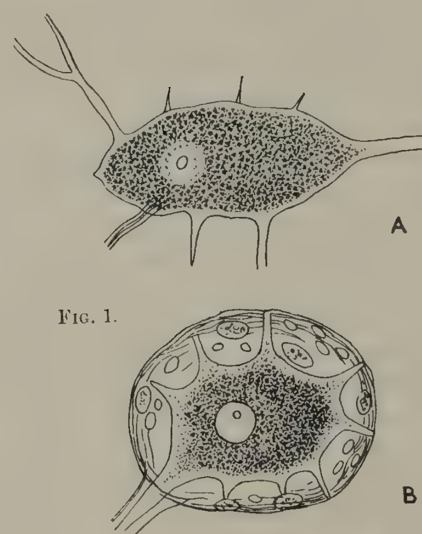


Fig. 1.

Fig. 4.

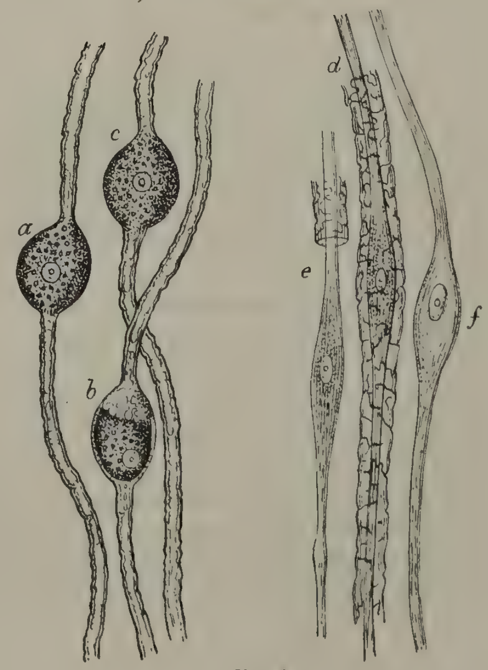


Fig. 3.

There is a direct mode of communication between the cosmos objectively considered, and the several parts of the body subjectively considered.

The nervous system is conveniently subdivided into sympathetic and cerebro-spinal nerves, according as they exercise no volition, very little volition, or a full measure of volition.

The nervous system is further divided into the cerebro-spinal, connected with volition, and the sympathetic, connected with the vegetative processes of the body, and very little, if at all, with the powers of volition.

It is not possible to draw a line of demarcation between the cerebro-spinal and sympathetic systems, as the one runs into the other at various points.

Neither can the spinal cord be separated from the cerebrum or brain proper.

The brain is an expansion of the spinal cord, and the nerve elements found in the one are also found in the other. These may, or may not, be slightly modified. The ganglia of the spinal cord have accessories akin to those of the brain, and may not inappropriately be designated brainlets or little brains.

The spinal cord and brain are composed of two substances; the one consisting of grey nerve matter, the other of white nerve matter. The grey substance occupies an interior position in the cord, and an exterior one on the surface of the brain. The white nerve matter, on the contrary, occupies an exterior position in the cord and an interior one in the brain. The grey matter is largely ganglionic in character.

The grey nerve substance is chiefly employed in the transmission of nerve impulses, especially motor impulses. The white nerve substance is mainly concerned in the transmission of sensory impressions.

It will be evident from what is now stated that the nervous system of the higher animals is composed of a highly complex machinery, which may work as a whole or in parts. It has only to be added, that the normal action of the nervous system necessitates a healthy body and healthy surroundings.

PLATE CXXVII

Plate cxxvii. shows the several nerve cells and ganglia in the spinal cord and brain of man.

Fig. 1.—A. Nerve cells from a lumbar sympathetic ganglion of an adult man, without a sheath.
B. The same with a sheath. The cell substance contains pigment of a vivid yellow tint, and is consequently darkly granular (after Max Schultze).

Fig. 2.—Roots of a spinal nerve. *a*, Structure of ganglion on posterior or sensory root, showing connections with nerve fibres; *b*, anterior or motor root (after Leydig).

Fig. 3.—A. Three bipolar ganglion cells, from the Gasserian ganglion of the pike (*a*, *b*, *c*) (after Bidder).
B. Three bipolar ganglion cells, from the auditory nerve of the pike. At *d*, they are invested by the medullary sheath; at *e*, they are partially exposed; and at *f*, they are wholly exposed. This figure shows the ganglion cells to be mere dilatations of the axis cylinder (after Max Schultze).

Fig. 4.—A. Nerve cells and processes from the spinal cord in man. *a*, Nerve cell; *b*, pigment mass; *c*, a nerve process. From the anterior cornu of the spinal cord of man, × 150 (after Gerlach).
B. *a*, *b*, *c*, Nerve cells from the longitudinal section of the spinal cord of a calf, treated with carmine and ammonia; *d*, *d*, nerve processes running horizontally forwards, × 150 diameters (after Gerlach).

Figs. 5 and 7.—Sections of the cortex cerebelli, stained by Golgi's method. Fig. 5, section taken across the lamina. Fig. 7, section made in the direction of the lamina.
A. Outer or molecular layer. B. Inner or granule layer. C. Medullary centre. *a*, Corpuscle of Purkinje; *b*, small granules of inner layer; *c*, a protoplasmic process of a granule; *d*, nerve fibre process of a granule passing into the molecular layer, where it bifurcates and becomes a longitudinal fibre (in Fig. 5 these longitudinal fibres are cut across and appear as dots); *e*, bifurcation of another fibre; *g*, a granule lying in the white centre.

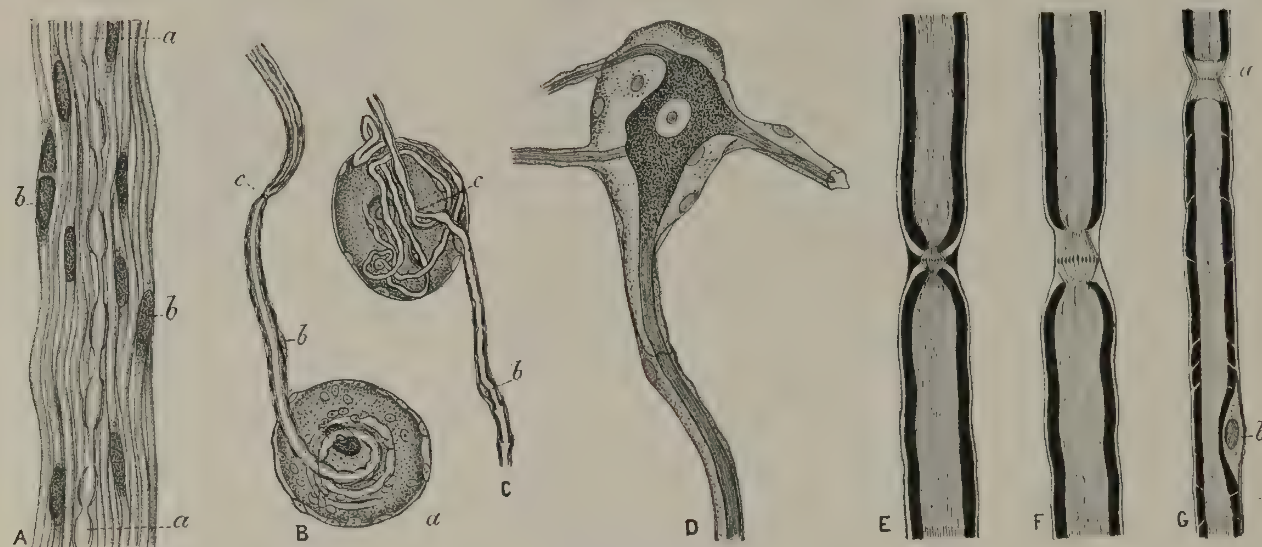
Fig. 6.—*ι*, Axis cylinder or nerve fibre process of one of the corpuscles of Purkinje; *b*, fibres prolonged over the beginning of the axis cylinder process; *c*, branches of the nerve fibre processes of cells of the molecular layer, felted together around the bodies of the corpuscles of Purkinje (after Ramon y Cajal).

PLATE CXXVIII

Plate cxxviii. illustrates the formation of nerve fibres, nerve cells, and ganglia as seen in the sympathetic and cerebro-spinal systems, with and without their sheaths, in the human subject, and in the pigeon; also the nervous system of the pig and snail; likewise plexus of nerve fibres and blood-vessels.

Fig. 1.—A. A small bundle of nerve fibres from the sympathetic nerve. *a*, *a′*, Nerve fibre enclosed here and there by a medullary sheath; *b*, *b′*, nuclei of pale fibres (after Key and Retzius).
B. and C. Two nerve cells from a human spinal ganglion. *a*, Nucleated sheath; *b*, *b′*, nuclei of the primitive sheath of the nerve; *c*, bifurcation of nerve (after Key and Retzius).
D. Ganglion cell within its sheath, from the human sympathetic. Highly magnified (after Key and Retzius).

PLATE CXXVIII



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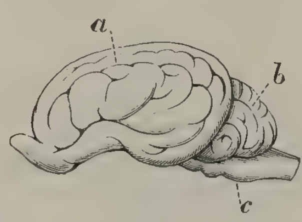

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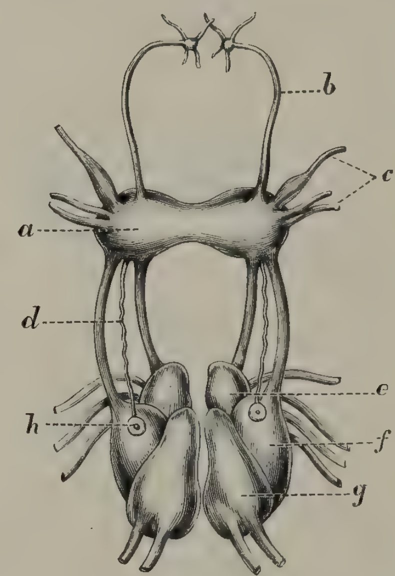

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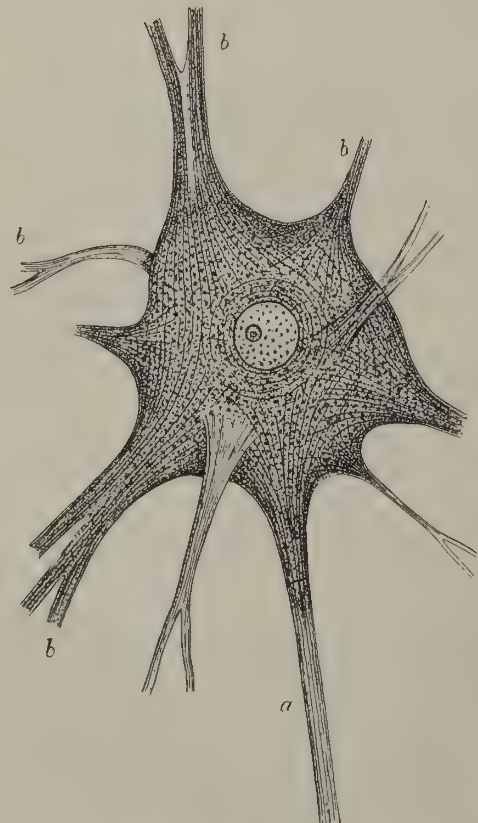

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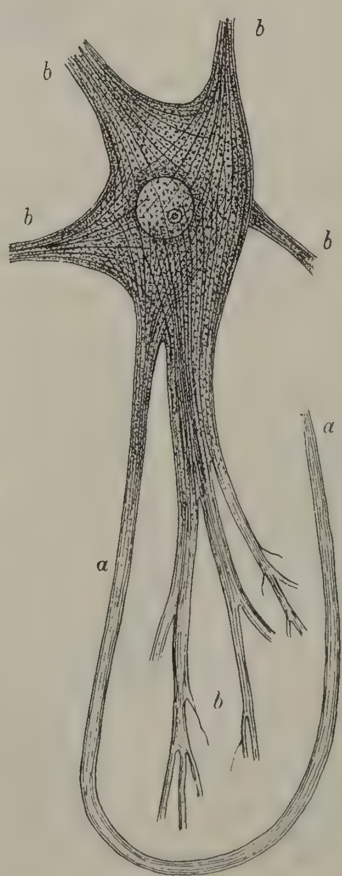

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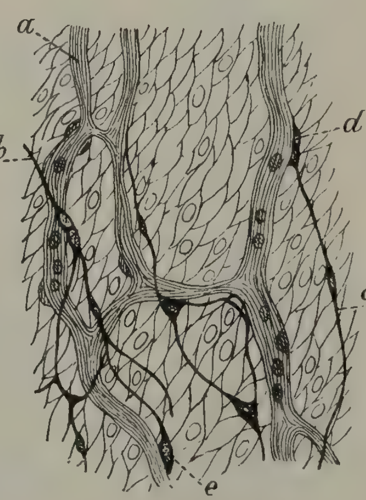
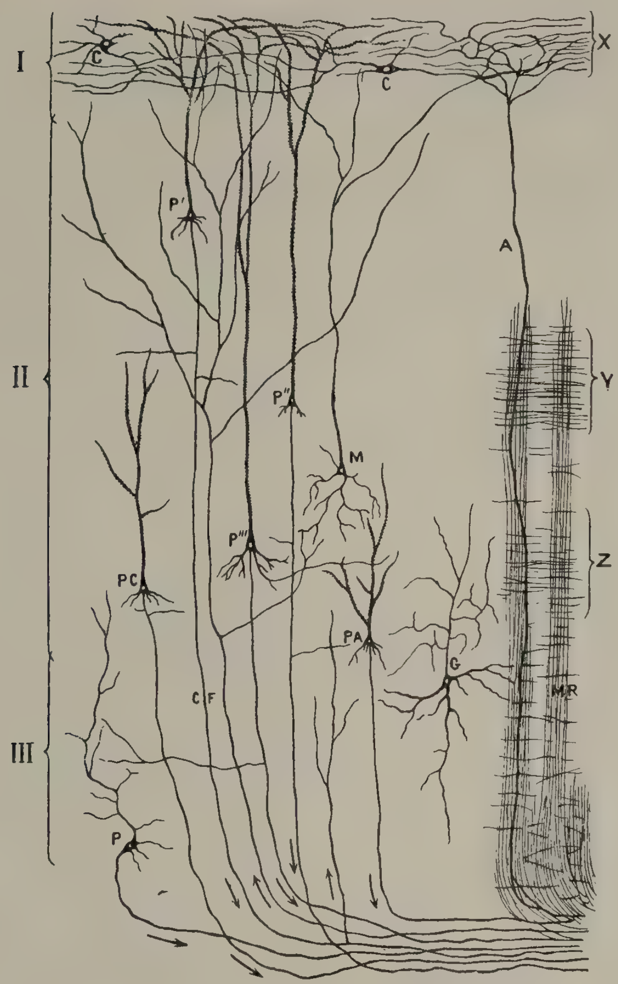


FIG. 6.

PLATE CXXIX



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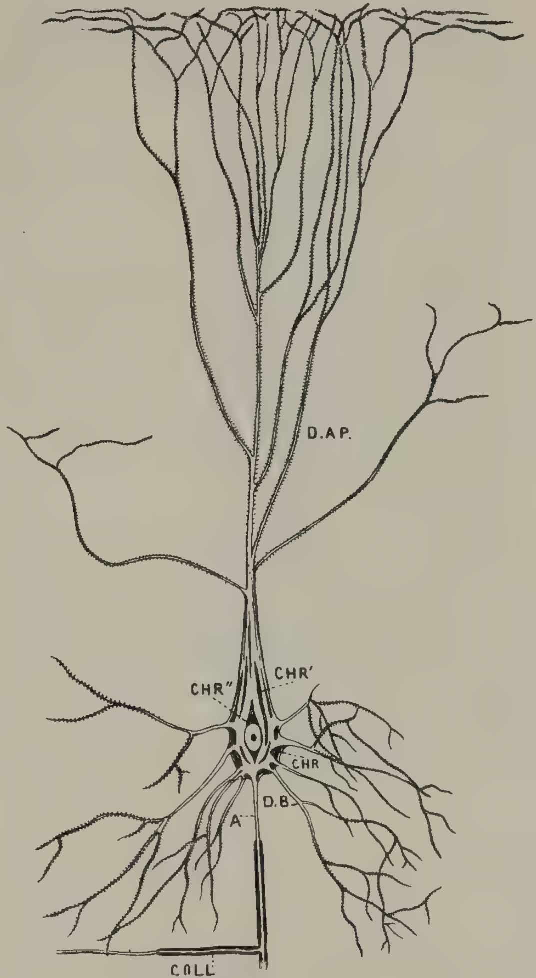

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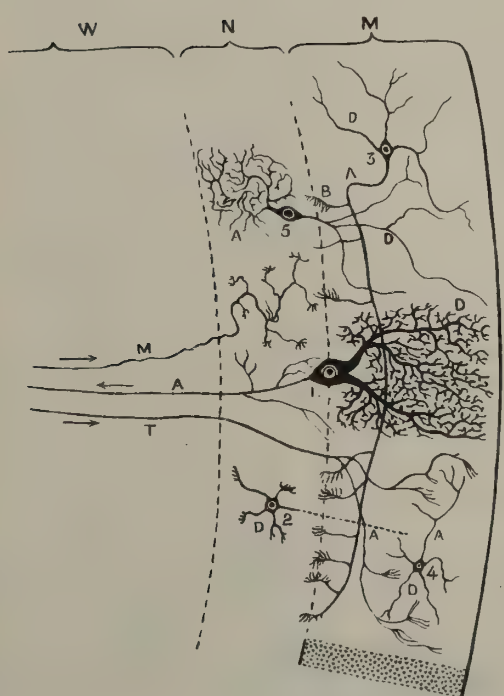

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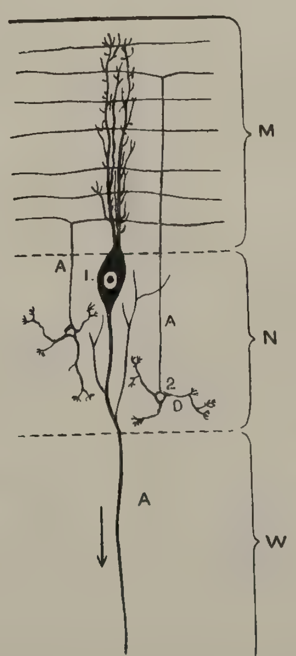

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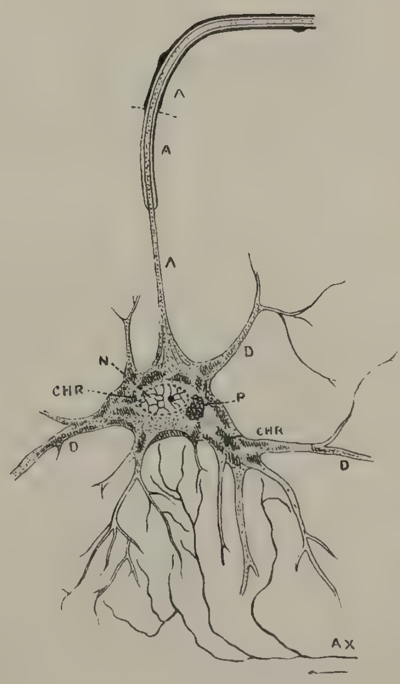


Fig. 5.

PLATE CXXVIII (*continued*)

E. and F. Nodes of Ranvier from the nerve of a pigeon, treated with osmic acid. The medullary sheath is stained black. The fibrils of the axis-cylinder have enlargements at the middle of the node. In E the constricting band is seen.

G. Medullated nerve fibre, treated with osmic acid. *a*, Node of Ranvier; *b*, nucleus (after Key and Retzius).

Fig. 2.—Brain of the domestic pig (*Sus scrofa*). *a*, Convolutions of brain (these are well marked); *b*, convolutions of cerebellum; *c*, medulla oblongata.

Fig. 3.—The nervous system of the snail (*Macrocyclis concava*), removed entire, and viewed from the dorsal side. *a*, Cerebral ganglion; *b*, buccal nerve; *c*, nerves to tentacles; *d*, nerve to otocyst; *e*, pedal ganglion; *f*, pleural ganglion; *g*, visceral ganglion; *h*, otocyst (after Howes).

Fig. 4.—Ganglion cells from the electric lobes of the brain of the torpedo (*Torpedo vulgaris*), medium-sized specimen, × 600. *a*, Axis-cylinder process; *b*, *b*, *b*, *b*, arborescent processes. Recent. After short maceration in serum containing a little iodine. Shows granular contents of ganglion, nucleus, and nucleolus (after Max Schultze).

Fig. 5.—A medium-sized ganglion cell from the anterior horn of the spinal cord of the calf. *a*, Axis-cylinder; *b*, *b*, *b*, *b*, *b*, arborescent processes abruptly broken off (after Max Schultze).

Fig. 6.—Plexus of capillary blood-vessels and nerves. *a*, Capillary blood-vessels; *b*, *c*, nucleated nerve fibres which are attached to the capillary walls at *d*, *e* by a pyriform enlargement. From a specimen taken from man and prepared with chloride of gold (after Kessel).

PLATE CXXIX

Plate cxxix. shows figures and diagrams of nerve cells, ganglia, &c. of the brain of a mammal.

Fig. 1.—I, Molecular layer; II, layer of pyramid cells; III, layer of polymorphous cells; P′, P″, P‴, pyramid cells; PA, a pyramid cell whose axon reaches an adjoining region of cortex as an association fibre; PC, a pyramid cell whose axon passes to the opposite hemisphere (*via* corpus callosum or anterior commissure) as a commissural fibre; M, a cell ("Martinotti cell") whose axon runs outwards towards the surface of the cortex; G, a cell ("Golgi cell") with a short, much-branched axon—the axon is not always turned upwards as in the instance figured; C, a "polygonal" cell of the molecular layer; GC′, a "fusiform" cell of the molecular layer; A, an "association" or "commissural" nerve fibre, the axon of a distant cell; CF, a nerve fibre, the axon of a cell belonging to the fillet or the optic thalamus; P, a cell of the polymorphous layer; MR, medullary ray of medullated fibres; X, outermost layer of tangential fibres; Y, middle layer of tangential fibres (Gennari's band); Z, inner layer of tangential fibres (Baillarger's band) (Michael Foster).

Fig. 2.—Diagram of a pyramid cell. A, Axon with COLL, collateral; D.B., basal dendrites; D.AP., apical dendrites; CHR, CHR′, CHR″, the three kinds of chromatin spindles in the perikaryon (Michael Foster).

Fig. 3.—Diagram of a section of a leaflet of the cerebellum taken in the transverse plane. M, Molecular layer; N, nuclear layer; W, white matter; 1, cell of Purkinje; 2, spider-like cell of the nuclear layer; 3, basket-cell; B, a basket (for the sake of clearness the basket belonging to the particular Purkinje cell shown in the figure has been omitted); 4, other cells in the molecular layer; 5, cell of Golgi; T, tendril fibre; M, moss fibre; A, axon; D, dendrite in the case of each cell. The arrows indicate the assumed direction of nervous impulses. In the lowest part of the figure is shown the punctuated appearance of the molecular layer as seen in transverse section.

Fig. 4.—The same as Fig. 3, taken in the longitudinal plane. Both figures are wholly diagrammatic (Michael Foster).

Fig. 5.—Diagram of a neuron with perikaryon, dendrites (D, D, D), and axon. The perikaryon contains nucleus (N), pigment (P), and chromatic substance (CHR). Note the absence of the latter from the axon. The axon acquires a myelin sheath; then, outside the cord, a primitive sheath. A is the termination of the axon of another cell approaching close to the perikaryon and dendrites of the neuron figured (after Michael Foster).

PLATE CXXX

Plate cxxx. gives examples and the exact locality, &c., of various kinds of nerve cells in the cerebrum, cerebellum, and spinal cord of several mammals.

Fig. 1.—Section of cerebral convolution (after Meynert). 1, Superficial layer, with scattered cells; 2, layer of small pyramidal cells; 3, broader layer of pyramidal cells, separated into columns by the radiating nerve fibres; 4, narrow layer of small irregular cells; 5, layer of fusiform and irregular cells in medullary centre.

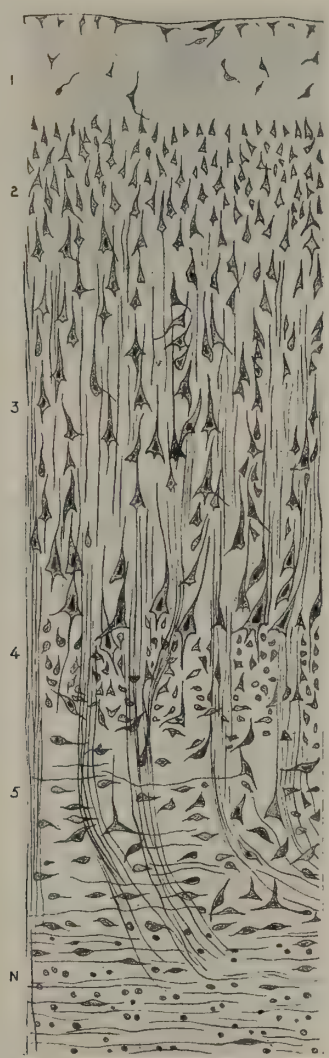
Fig. 2.—Cells from the cerebral cortex, shown by Golgi's method. N, N, Neuroglia cells; P, P, pyramids; A, A, axis-cylinder processes of pyramids giving off collaterals (after G. Retzius).

Fig. 3.—Section of cortex of cerebellum. A, Pia mater; B, external layer; C, layer of corpuscles of Purkinje; D, inner or granule layer; E, medullary centre (after Sankey).

Fig. 4.—Section of cerebellar lamina of a fifteen-day kitten, showing some of the neuroglia elements. Golgi's method. A, Pia mater; B, processes of the neuroglia cells passing towards the surface, where they end in conical enlargements; C, E, elongated neuroglia cells; D, stellate neuroglia cell (after Ramon y Cajal).

Fig. 5.—Diagram showing the probable relations of some of the principal cells and fibres of the cerebro-spinal system to one another (E. A. S.). 1, A cell of the cortex cerebri; 2, its axis-cylinder or nerve process passing down the pyramidal tract, and giving off collaterals, some of which (3) end in arborisations around cells of the anterior horn of the spinal cord, the main fibre having a similar ending at 4; CALL., a collateral passing in the corpus callosum to the cortex of the opposite side; STR., a collateral passing into

PLATE CXXX



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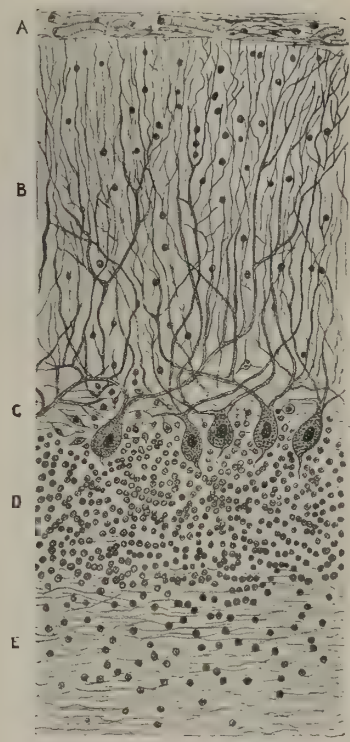

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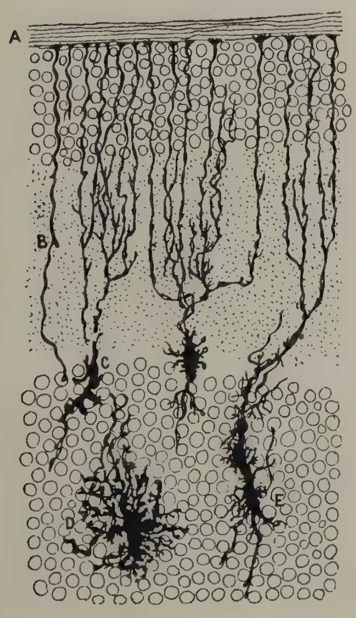

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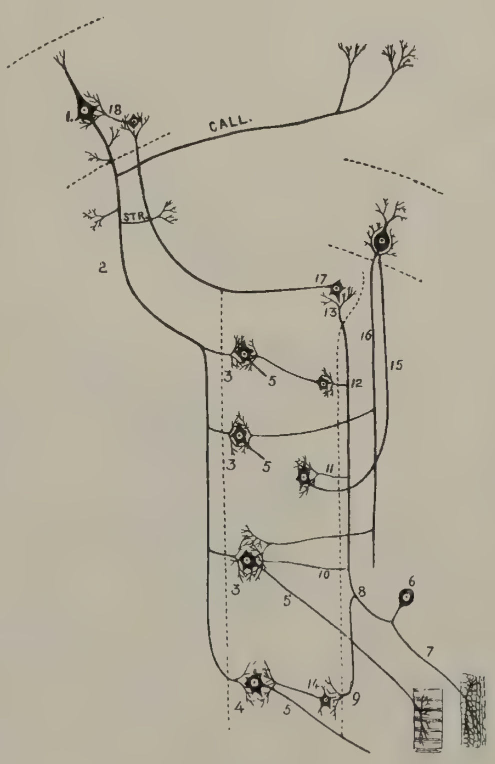


Fig. 5.

Fig. 6.

PLATE CXXX (*continued*)

the corpus striatum; 5, axis-cylinder process of anterior cornu-cell passing to form a terminal arborisation in the end-plate of a muscle fibre (M). 6, A cell of one of the spinal ganglia. Its axis-cylinder bifurcates, and one branch (7) passes to the periphery to end in an arborisation in the sensory surface. The other (central) branch bifurcates after entering the cord (at 8), and its divisions pass upwards and downwards (the latter for a short distance only). 9, Ending of the descending branch in a terminal arborisation around a cell of the posterior horn, the axis-cylinder process of which, again, ends in a similar arborisation around a cell of the anterior horn; 10, a collateral passing from an ascending division directly to envelop a cell of the anterior horn; 11, one passing to envelop a cell of Clarke's column; 12, a collateral having connections like those of 9; 13, ending of the ascending division of the posterior root-fibre around one of the cells of the posterior columns of the bulb; 14, axis-cylinder processes of cells of the posterior horn passing to form an arborisation around the motor cells; 15, a fibre of the ascending cerebellar tract passing up to form an arborisation around a cell of the cerebellum; 16, axis-cylinder process of this cell passing down the bulb and cord, and giving off collaterals to envelop the cells of the anterior horn; 17, axis-cylinder process of one of the cells of the posterior column of the bulb passing as a fibre of the fillet to the cerebrum, and forming a terminal arborisation around one of the smaller cerebral cells; 18, axis-cylinder process of this cell, forming an arborisation around the pyramidal cell (1).

FIG. 6.—*a*, A nerve fibre dividing into two branches (*b*, *b*), which communicate with the plexuses of nerve fibres (*c*, *c*) in connection with the two nerve cells (*d*, *d*). Prepared with carmine and ammonia from the spinal column of an ox, × 150 (after Gerlach).

PLATE CXXXI

This plate shows a simple cell, and how the nervous system is constructed in the star-fish, Aplysia, and centipede. It also shows how the brain of the fish, reptile, bird, and mammal are built up; likewise how the brain is formed, and that there is a striking resemblance between the formation of the vertebrate spinal column and the double chain of ganglia connected by longitudinal commissural nerve fibres in the centipede. It also reveals the origins of the cranial nerves in man, and the position of the great nerve centres at the base of the brain.

FIG. 1.—Typical cell, consisting of a cell wall or envelope, a nucleus, and a nucleolus. *a*, Cell wall; *b*, cell contents; *c*, nucleus; *d*, nucleolus. The darts *e*, *f* represent the endosmotic or ingoing nutrient currents, by which the cell is fed; the darts *g*, *h* the exosmotic or outgoing currents, whereby the cell rids itself of waste products and injurious substances. The cell wall, cell contents, nucleus, and nucleolus are osmotic media, and, when the cell is placed in suitable fluids, its vital and mechanical properties are at once evoked (the Author).

FIG. 2.—A. The nerve arrangements in the five-rayed brainless star-fish, consisting of a circular commissural nerve ring with five nerve centres or ganglia (one at the foot of each limb). Each ganglion receives and gives off sensory and motor nerves. *a*, Commissural nerve ring surrounding the mouth of the star-fish; *b*, oral aperture of star-fish; *c*, one of the five triangular-shaped ganglionic masses; *d*, motor nerves; *e*, sensory nerves. The star-fish in virtue of its nerve arrangements can receive sensory impressions from without and send out motor impulses from within. The animal can feel and move voluntarily, and is in no sense dependent for its movements on inherent irritability, stimulation, or so-called reflex action. The five-rayed star-fish and its nervous system are symmetrical (after Dalton).

B. The aplysia—an unsymmetrical mollusc—with an unsymmetrical nervous system. In the aplysia a rudimentary brain makes its appearance. The cephalic or brain ganglion is composed of two small ganglionic masses fused together and connected with the ganglionic nerve centres in all the other parts of the body by means of commissural nerve fibres. The ganglia receive and give off sensory and motor nerve fibres, and the animal can, like the star-fish, feel, and move to given ends, irrespective of inherent irritability, artificial stimulation, and so-called reflex action. *a*, Digestive or œsophageal ganglia; *b*, cephalic or cerebral ganglia; *c*, *c*, pedal or locomotory ganglia; *d*, respiratory ganglion. The nervous system of the aplysia is symmetrical in the upper and asymmetrical in the lower part of the body.

FIG. 3.—A. Illustrates the nervous system of the centipede (*Scolopendra*). It consists of a double chain of ganglia connected together by longitudinal and transverse nerve commissures; two ganglia with sensory and motor nerves being provided for each articulation of the animal. The cephalic ganglia are increased in size and united to form a fairly well developed brain. The brain of the centipede sends nerves to the antennæ and to the organs of special sense. *a*, Brain, composed of two symmetrical portions united longitudinally and transversely by nerve commissures; *c*, *c′*, the longitudinal commissural fibres of the left side of the nervous system.

B. Illustrates the nervous system of man (*Homo sapiens*). The human nervous system is usually divided into a cerebro-spinal and sympathetic portion—the former only being here represented. The cerebro-spinal system closely resembles that of the centipede, which furnishes its type. It consists of two symmetrical halves, with collections of ganglia corresponding to the segments of the body. The ganglia are provided with sensory and motor nerves, and are united longitudinally and transversely by nerve commissures to secure harmonious working. The peculiarity of the cerebro-spinal system in man is the enormous expansion of the cerebro-spinal lobes or hemispheres, which grow upwards, forwards, and backwards, and so cover in the great ganglionic nerve centres situated at the base of the brain. *a*, Cerebral lobes or great brain (cerebrum); *b*, cerebellum; *c*, cervical portion of spinal cord; *c′*, dorsal portion of spinal cord; *d*, brachial plexus and nerves going to the arms; *e*, lumbar plexus and nerves going to the legs.

FIG. 4.—Illustrates the comparative anatomy of the brain and spinal cord in the fish, reptile, and mammal. The brain and spinal cord are divided longitudinally into two portions, and are bi-laterally symmetrical.

A. The brain and beginning of spinal cord of cod-fish. *a*, Olfactory lobes, two in number; *b*, cerebral lobes or hemispheres, also called cerebrum; *c*, middle brain, giving rise to the optic nerves; *d*, cerebellum; *e*, spinal cord with swelling (medulla oblongata).

B. Brain of hammer-headed shark. The lettering is the same as in A (after Dallas).

C. Brain of alligator. *a*, Olfactory ganglia; *b*, cerebral ganglia or hemispheres; *c*, optic tubercles; *d*, cerebellum; *e*, expansion of the spinal cord into the medulla oblongata.

D. Brain of rabbit. *a*, Olfactory bulbs or ganglia; *b*, cerebral ganglia or hemispheres, separated to show the corpora striata (*c*), optic thalami (*d*), and tubercula quadragemina, situated behind the optic thalami (*d*); *f*, cerebellum; *g*, spinal cord swelling into the medulla oblongata (after Dalton).

PLATE CXXXI

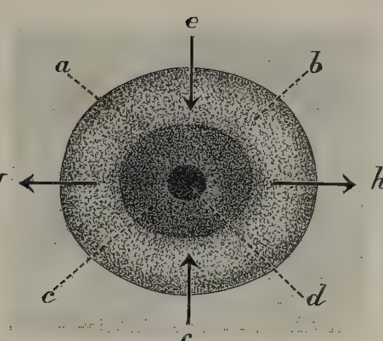


Fig. 1.

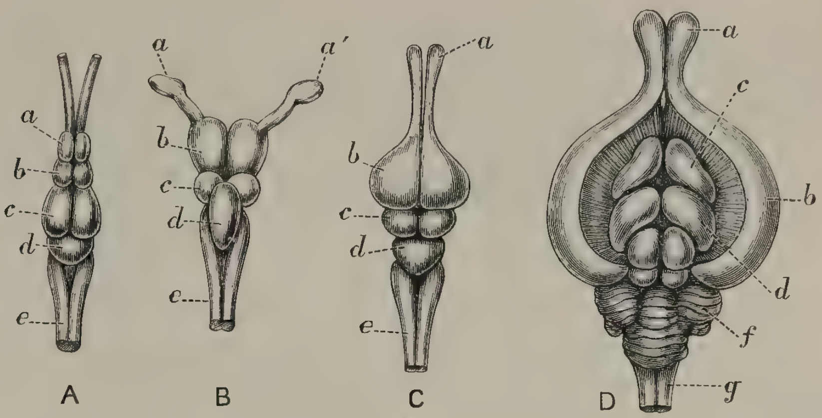


Fig. 4.

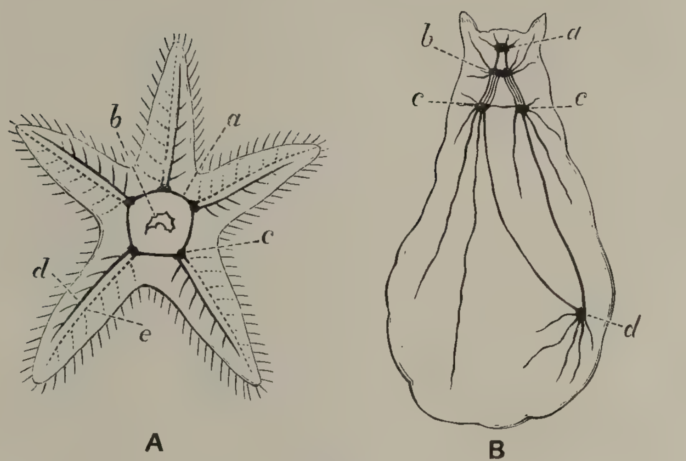
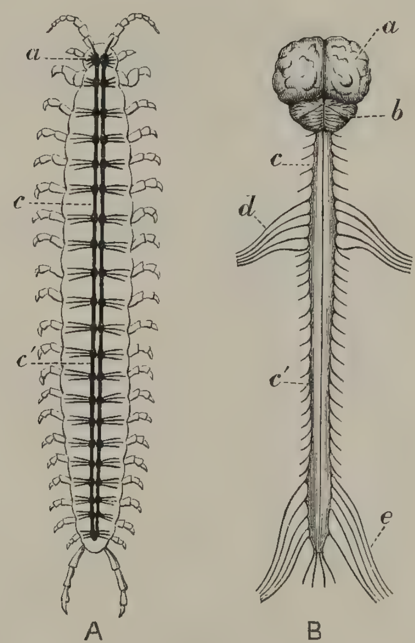


Fig. 2.



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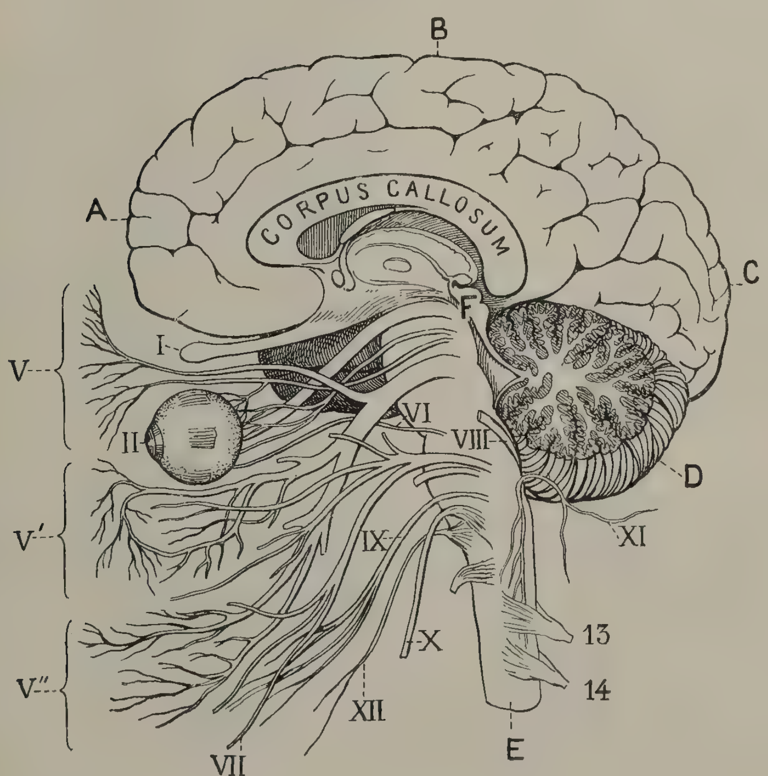


Fig. 5.

Fig. 6.

PLATE CXXXI (*continued*)

FIG. 5.—Brain and cephalic nerves of man, shown in vertical section through the median plane. A, Anterior; B, middle; C, posterior lobes of brain; D, cerebellum; E, spinal cord; F, corpora quadragemina (origin of optic nerves); I, olfactory bulb; II, eye with optic nerve; V, V′, V″, fifth pair of nerves, trifacial or trigeminal; VI, sixth pair, abducent ocular; VII, seventh pair, facial motor; VIII, auditory nerve; IX, glosso-pharyngeal nerve; X, par vagum or pneumogastric; XI, spinal accessory; XII, hypoglossal or lingual motor; 13 and 14, ordinary double rooted spinal nerves (after Carpenter).

FIG. 6.—Hippocampus of human brain. *a*, *a′*, Anterior cornu of hippocampus; *b*, anterior cornu of middle hippocampus; *c*, *c′*, anterior cornu of posterior hippocampus (after Gray).

PLATE CXXXII

This plate illustrates the sympathetic and cerebro-spinal systems as seen in man (*Homo sapiens*). The sympathetic system is seen to occur on either side of the spinal column, and is remarkable for the number of ganglia displayed by it. There is a ganglion for the root of each rib, showing the segmented nature of the human trunk. This plate also shows that the cord is divided into two portions, and is bi-laterally symmetrical; the same is true of the encephalon. It is composed of grey and white nerve substance, the former being placed inside and the latter outside the cord, as shown in several figures. The brain is also in two halves; the grey matter in this case being outside and the white inside. Lastly it shows that the medulla oblongata, cerebellum, and cerebrum are expansions of the spinal cord; the spinal cord and brain proper forming one system.

FIG. 1.—Anterior view of the brain, spinal cord, sensory and motor nerves, sympathetic system of nerves, &c.

A, A′. Spinal cord with anterior median fissure.
B. Expansion of the medulla oblongata.
C. Pons varolii.
D. Anterior lobe of brain.
E. Middle lobe of brain.
F. Posterior root of sensory nerve with ganglion.
G. Anterior root of motor nerve.
H. Mixed nerve containing sensory and motor fibres.
I. Bulb of olfactory nerve.
J. Optic nerve.
K. Common oculo-motor nerve.
L. Roots of trigeminal nerve.
M. External oculo-motor.
N. Facial and auditory nerve.
O. Eighth pair of nerves formed by the glosso-pharyngeal, pneumogastric, and spinal nerves.
P. Cervical portion of the chain of the great sympathetic nerve, formed by the superior, middle, and inferior cervical ganglia and their branches of communication, with cervical plexus.
Q. Great hypoglossal nerve.
R. Spinal ganglion.
S Brachial plexus.
T. Lumbar plexus.
U. Sacral plexus.
V. Anastomosis of the thoracic ganglia with the thoracic nerves.
W. Anastomosis of the lumbar ganglia with the lumbar and sacral nerves.
X. Coccygeal ganglion.
Y. Splanchnic nerve.

Note.—The numerals from 1 to 12 indicate the ribs.

FIG. 2.—Transverse sections of spinal cord in the cervical, dorsal, lumbar, sacral, and coccygeal regions. Shows the grey matter (coloured dark in figure) of the cord to occupy an internal position, and to be arranged in two halves symmetrically. The halves are crescent-shaped and connected in the middle by a nerve commissure. The cervical portions of the cord are indicated by the letter C, and the numbers 1 to 8 inclusive; the dorsal portions are indicated by the letter D, and the numbers between 1 and 12; the lumbar portions are indicated by the letter L, and the numbers 1, 3, and 5; the sacral portions are indicated by the letter S, and the numbers 2 and 4; finally, the coccygeal portion of the cord is indicated by the letters Co, and the number 1 (after Gowers).

FIG. 3.—Transverse sections of cervical portion of human spinal cord, showing the grey ganglionic nerve centres with their sensory and motor nerves. The grey ganglionic matter is arranged in two symmetrical crescentic masses within the cord, this being united longitudinally and transversely by nervous commissures. The sensory and motor nerves are connected with the free extremities (horns) of the crescentic grey substance.

The cord is divided into two portions by anterior and posterior fissures. It is further divided by the grey crescentic matter of the cord, and the ingoing and outcoming sensory nerves, so that they may be said to consist of six longitudinal columns.

In the figures the same numerals indicate the same parts.

A. Anterior view of spinal cord.
B. View of right side of cord.
C. Upper surface of cord.
D. The nerve roots and ganglia seen from below.

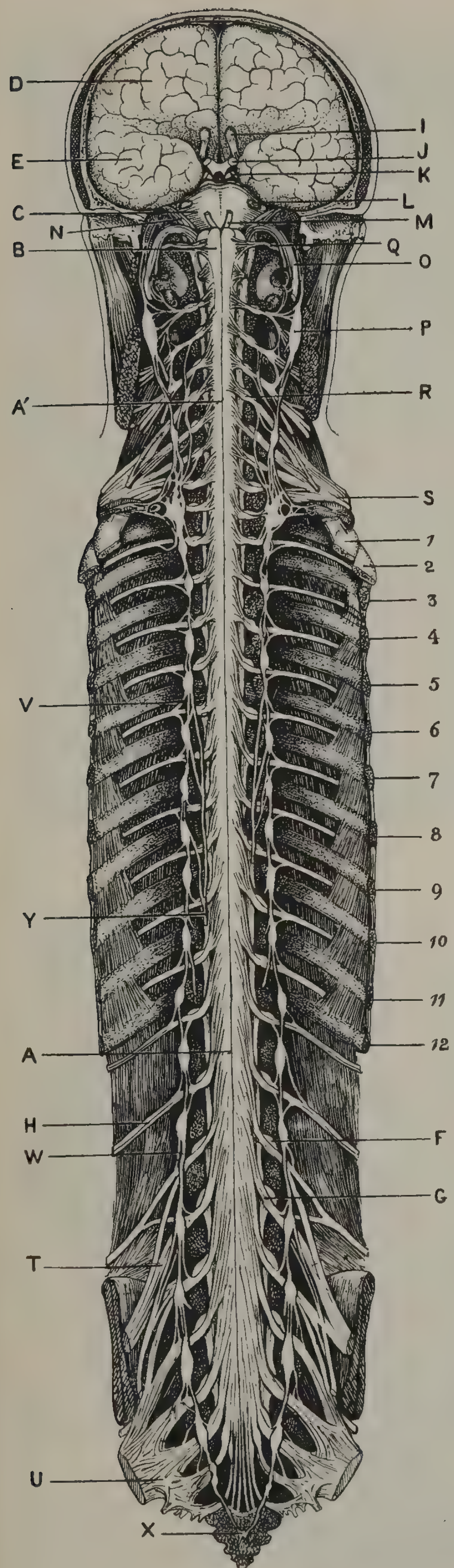
1, Anterior median fissure of cord; 2, posterior ditto; 3, antero-lateral depression; 4, posterior lateral groove into which the posterior sensory nerve (6) disappears; 5, anterior motor nerve sinking into antero-lateral depression of the cord—these fibres display a ganglionic swelling (6′) in their course; 7, the united compound or mixed nerve—is divided partly; 7′, the posterior primary branch of same. This nerve is derived partly from the anterior and partly from the posterior roots of the spinal nerves (after Allen Thomson).

FIG. 4.—Diagram of human brain in mesial line section, showing the situation of the different ganglia, and the course of the nerve fibres.

A. Olfactory ganglion.
B. Hemisphere.
C. Corpus striatum.
D. Optic thalamus.
E. Tubercula quadrigemina.
F. Cerebellum.
G. Ganglion of tuber annulare.
H. Ganglion of medulla oblongata (after Dalton).

FIG. 5.—Diagram of the probable course and relations of some of the optic fibres (after Ramon y Cajal).

PLATE CXXXII



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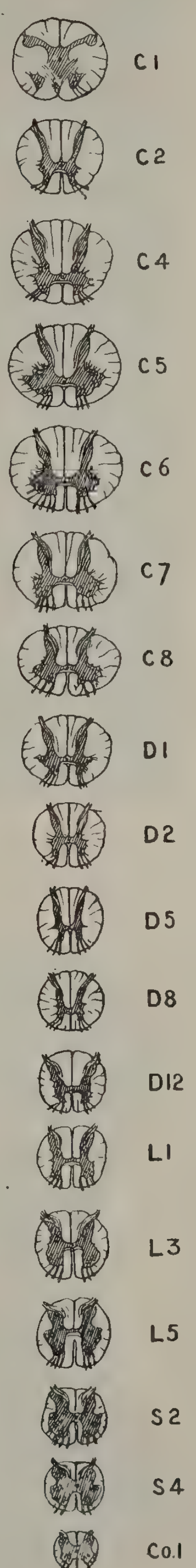

FIG. 2.

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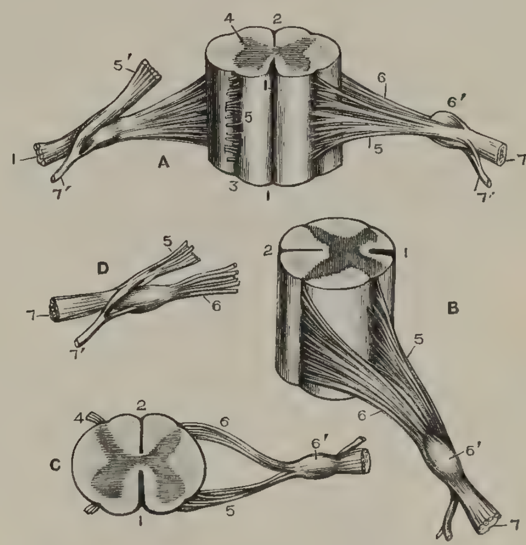

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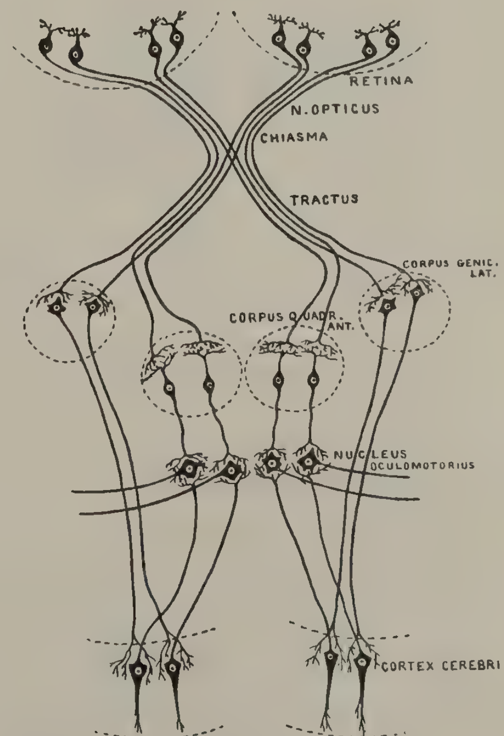


FIG. 5.

PLATE CXXXIII

Plate cxxxiii. shows what apparently is a law of development of living matter as seen in the convolutions of the surface of the human brain and those of the brain coral. It also shows how the several nerves are given off from the cerebro-spinal axis in twelve main divisions, and how there is community of structure and position in the grey and white matter of the cervical, dorsal, and lumbar portions of the cord. Lastly it shows the arrangement of nerve cells, the cells of Golgi, and the neuroglia cells in the brain of the frog.

FIG. 1.—External convolutions of the human brain. Shows folded plicate arrangement.

FIG. 2.—Neptune's brain coral (*Meandrina cerebriformis*), so named from the hard parts of the skeleton greatly resembling the convolutions of the human brain. The resemblance is so striking as to point to a common law of growth. It cannot be explained by mimicry (photographed by the Author).

FIG. 3.—Semi-diagrammatic view of a deep dissection of the cranial nerves on the left side of the head. The enumeration of the cranial nerves here adopted is that by Soemmerring (1778).[1] Soemmerring gives twelve pairs of cranial nerves. The modern synonyms indicating their uses are given in brackets. First pair (olfactory nerves); second (optic); third (common oculo-motor); fourth (pathetic or cochlear); fifth (trifacial or trigeminal); sixth (abducent ocular); seventh (facial motor); eighth (auditory); ninth (glosso-pharyngeal); tenth (pneumogastric or vagus); eleventh (spinal accessory); twelfth (hypoglossal or lingual motor). *a*, Supra-orbital branch of the fifth; *b*, nasal passing towards the anterior internal orbital canal, and giving the long root of the ciliary ganglion; *c*, termination of the nasal nerve; *d*, superior maxillary division of the fifth passing into the infra-orbital canal; *e*, the same issuing at the infra-orbital foramen and being distributed as inferior palpebral, lateral, nasal, and superior labial nerves; *f*, ganglion of Meckel and vidian nerve passing back from it; *g*, palatine and other nerves descending from it; *h*, lingual nerve; *h'*, its distribution to the side and front of the tongue and to the sublingual gland, to join the lingual nerve (*i*); *j*, trunk of the glosso-pharyngeal passing round the stylo-pharyngeus muscle after giving pharyngeal and muscular branches; *k*, its distribution on the side and back part of the tongue; *l*, hypoglossal nerve; *m*, its distribution to the muscles of the tongue; *n*, pneumogastric nerve; *o*, superior cervical ganglion of the sympathetic, uniting with the upper cervical nerves and giving at *p* the superior cardiac nerve; *q*, the trunk of the sympathetic; *r*, the middle cervical ganglion uniting with some of the cervical nerves, and giving at *s* the large and middle cardiac nerve; *t*, the continuation of the sympathetic down the neck (after Allen Thomson).

FIGS. 4, 5, and 6.—Sections of spinal cord in lower cervical, mid-dorsal, and mid-lumbar regions (E. A. S.). On the right side of each section the conducting tracts are indicated.

FIG. 7.—Diagram of the nerve cells of the cerebral hemisphere of the frog. I, Molecular layer; II, pyramid cell layer; III, ependyma. *a*, Horizontal cells of the molecular layer; *b*, *b*, pyramidal cells with basal axons curving upward to join the tangential fibres of the molecular layer; *c*, pyramidal cell with axon running down toward the ependyma, above which it runs, contributing to a rudimentary medullary layer of fibres; *d*, a Golgi cell; *n*, a neuroglia cell (after Foster).

PLATE CXXXIV

This plate illustrates the several brain areas connected with the sense organs in man and in the monkey (Macacus); also the relations of the nerve roots entering the cord, and the fibres of the white columns of the cord, to the nerve cells in the grey matter. It likewise shows how the motor nerves terminate in the muscles.

FIG. 1.—A. and B. Left hemisphere of the cerebrum of Macacus monkey viewed from its left side, and from above (natural size).
C. Mesial aspect of the left half of the brain of Macacus, displayed by section in the median sagittal plane and removal of the cerebellum (natural size).
The hatched and stippled parts of the surface show the regions of the cortex connected with movements of the FOOT, KNEE, ANUS, HIP, TAIL, TRUNK, and NECK respectively. The several positions of the areas of cortex connected with VISION and SMELL are indicated by the appropriate words.
The plane of section has passed through the corpus callosum, CC, CC, CC, and through the anterior commissure, C, sparing the left pillar of the fornix, F; behind it has bisected the anterior part of the pons, laying open the aqueduct, AQ (iter a tertio ad quartum ventriculum). OP, the optic commissure cut across; III, the root of the third cranial nerve; FR, the frontal pole; OC, the occipital pole; CN, the cuneus; PON, the precuneus; G.FN, G.FN, G.FN, the gyrus fornicatus; the unlettered fissure seen to form the upper boundary of this gyrus in its supra-callosal part is the calloso-marginal; PO.F., the parieto-occipital fissure.

FIG. 2.—The lateral surface of the right cerebral hemisphere of man in outline, to illustrate the cortical areas. Reduced from nature.

FIG. 3.—The mesial surface of the right cerebral hemisphere of man in outline, to illustrate the cortical areas.

FIG. 4.—Diagram to illustrate the relations of the entering nerve roots, and the fibres of the white columns of the spinal cord, to the nerve cells in the grey matter (E. A. S.).

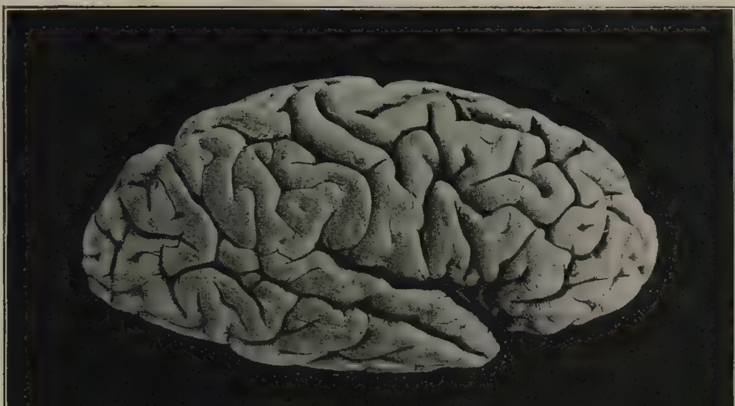
FIG. 5.—Transverse section of the spinal cord of a chick on the ninth day of incubation, prepared by Golgi's method.
A. Axis-cylinder of anterior root fibres issuing from large cells of the anterior horn, C.
B. Posterior root fibres passing from the bipolar cells of the spinal ganglion into the posterior column of the spinal cord (D), where they bifurcate (*d*) and become longitudinal: *e*, *f*, *g*, collaterals from these fibres passing into the grey matter (after Ramon y Cajal).

FIG. 6.—Muscular fibres, with nerve endings, from *Lacerta viridis*.
A. Seen in profile. *pp*, The terminal nerve plate; *ss*, the base or supporting plate, consisting of a granular mass with nuclei.
B. The same as seen in a perfectly fresh muscular fibre, whose nerve ends are still probably excitable. The delicate and pale contours which the frequently branched plate naturally possesses are not expressed in the woodcut (after W. Kühne).

[1] Willis (1664) divided the cranial nerves into nine pairs; the seventh, according to him, consisting of two parts, namely, the portio dura and the portio mollis. The eighth, in his opinion, also consisted of two parts, to wit, the n. vagus and the n. accessorius.

PLATE CXXXIII

Fig. 1.



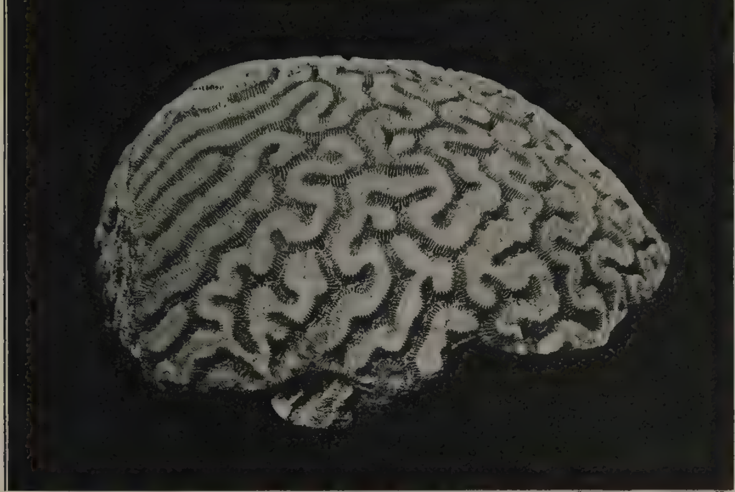
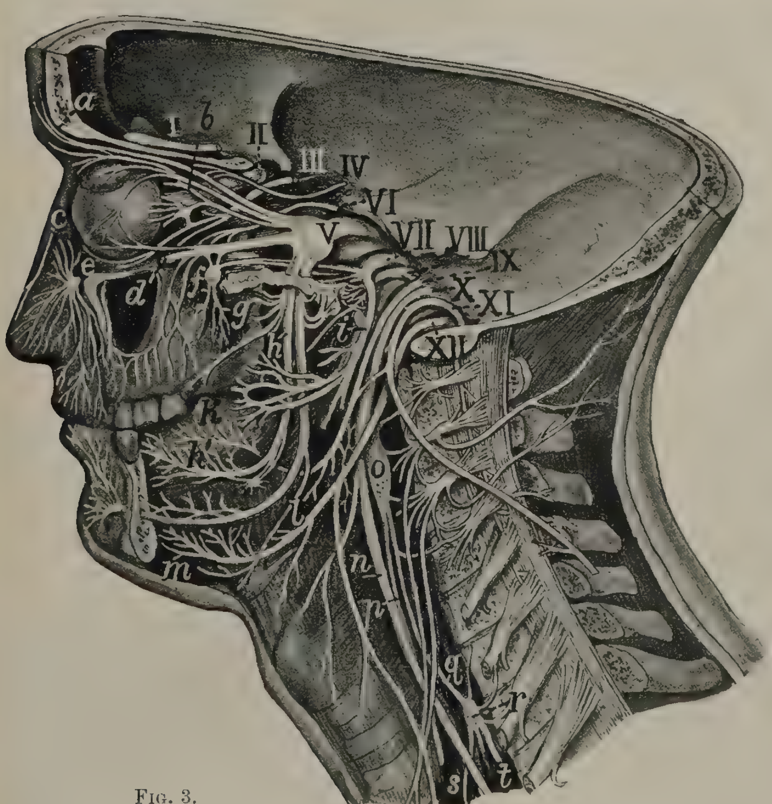


Fig. 2.



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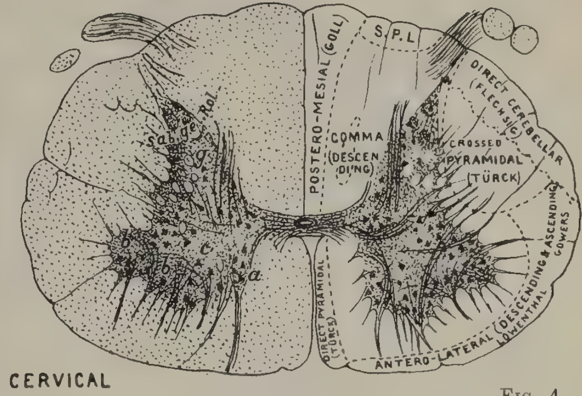

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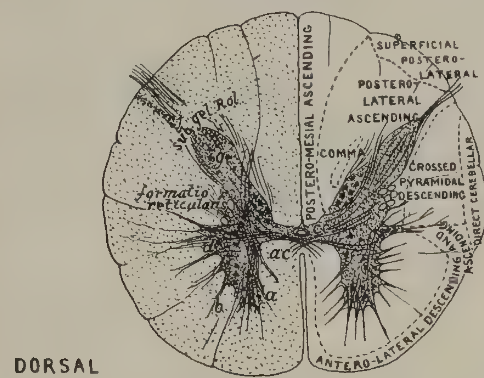

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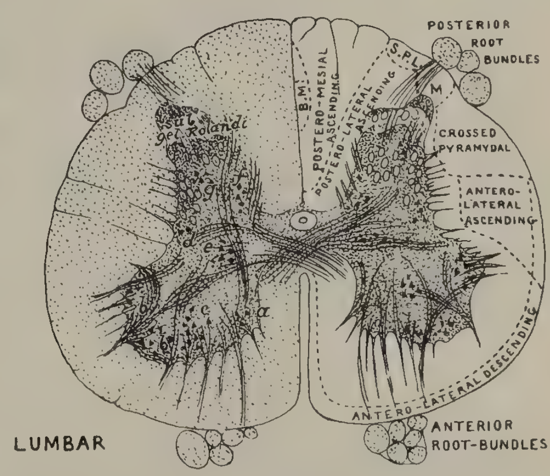

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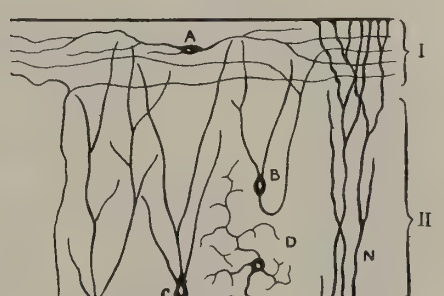


Fig. 7.

PLATE CXXXIV

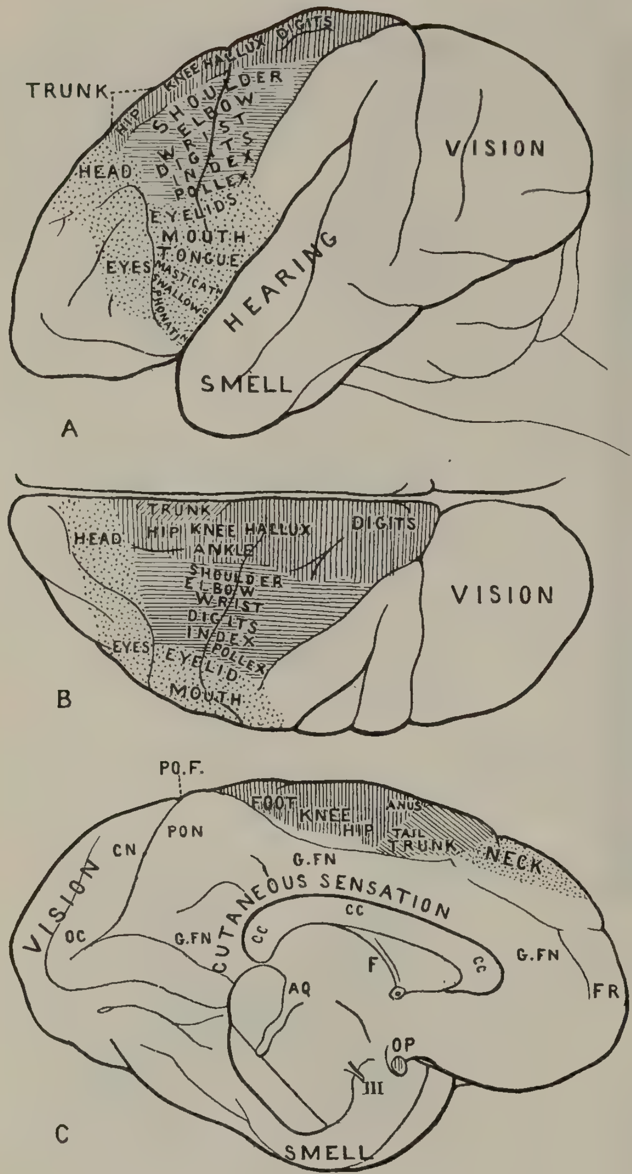
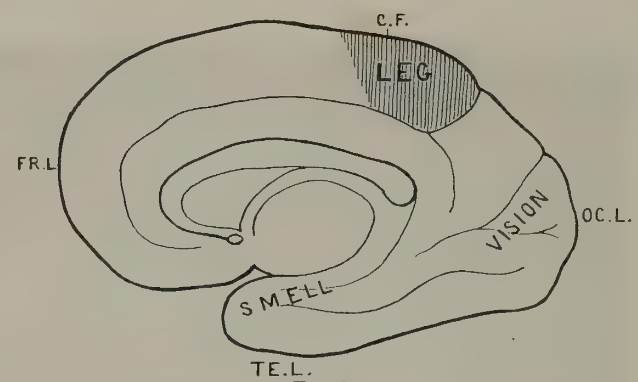


Fig 1.



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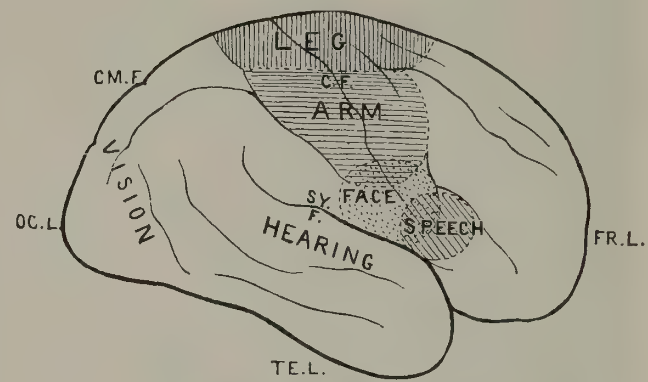
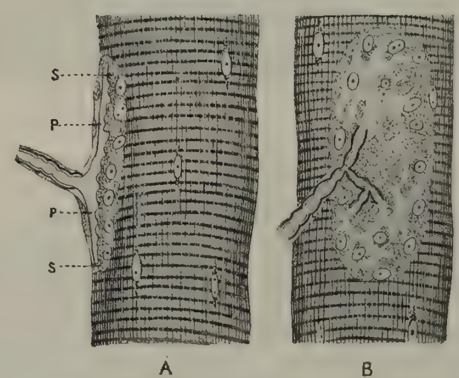


Fig. 3



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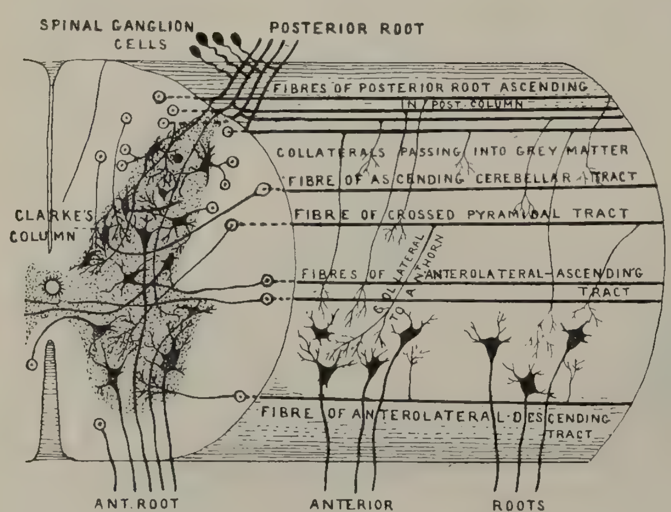


Fig. 4.

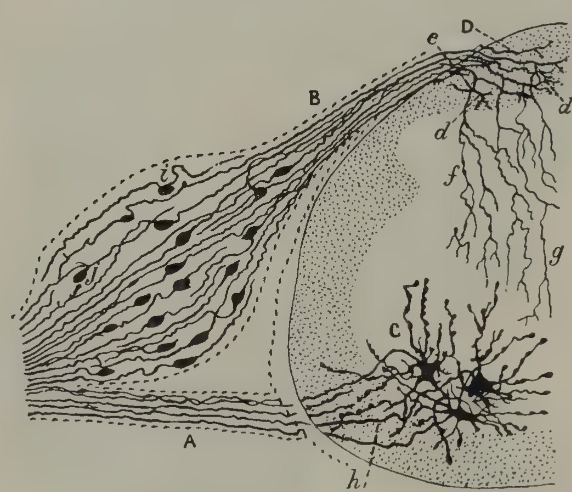


Fig. 5.

PLATE CXXXV

Plate cxxxv. illustrates the division of the nervous system into sensory and motor nerves in the cray-fish. Shows also ganglia in the frog, and nerve cells and epithelial cells in man.

FIG. 1.—A. The common cray-fish (*Astacus fluviatilis*, male) (after Huxley). Natural size. Shows radiation, branching, and segmentation in the limbs, claws, &c., and transverse division and segmentation of the body.

B. Dissection of the same from above, to show the central nervous system, sensory and motor nerves, &c. *a*, Supra-œsophageal ganglion; *b*, infra-œsophageal ganglion; *c*, fifth thoracic ganglion; *d*, last thoracic ganglion; *e*, last abdominal ganglion; *f*, optic nerve; *g*, antennulary nerve; *h*, antennary nerve; *i*, stomato-gastric nerve; *j*, circum-œsophageal commissures; *k*, œsophagus in cross section; *l*, vent.

FIG. 2.—Human foot.

FIG. 3.—Foot of anthropomorphous ape.

FIG. 4.—A. Ganglion cell of a frog, with right-handed spiral nerve fibres, magnified. *a*, *a*, Straight line; *b*, large coiling fibre; *c*, small coiling fibre (after Lionel S. Beale). Resembles twining plants (Plate x., Fig. 3, A).

B. Ganglion cell from the sympathetic system of the frog, with left-handed spiral nerve fibre, magnified. *a*, Straight fibre; *b*, coiling fibre, arising by a superficial netting connected with the nucleolus of the cell; *c*, *c*, capsule with nuclei (after J. Arnold). Resembles twining plants (Plate ix., Fig. 3, A and F, p. 22).

FIG. 5.—A. A group of olfactory cells from the *Proteus*, from a specimen prepared with Müller's fluid. *a*, Olfactory cells; *b*, epithelial cell lying within them; *c*, fine processes extending from cells, terminating in long, fine cilia (*d*).

B. An isolated olfactory cell, after treatment with a diluted solution of sulphuric acid (after Bubuchin).

C. Epithelial cells from the olfactory region of the *Proteus*. *a*, Olfactory cell; *b*, epithelial cell; *c*, fine process extending from the olfactory cell and terminating in fine cilia (*d*).

D. Epithelial and olfactory cells from man (after Max Schultze).

PLATE CXXXVI

Plate cxxxvi. illustrates various kinds of touch corpuscles in man, rabbit, &c.

FIG. 1.—Section of the skin of the hand magnified twenty times (modified Hirschfeld and Léveillé). Shows radiating, branching, and spiral structures.

A. *a*, Horny, and *b*, mucous layers of the epidermis; *c*, corium; *d*, panniculus adiposus; *e*, fat cells; *f*, spiral sweat glands opening on surface at *g*, *g*, *g*; *h*, nerve ending in Pacinian bodies (*i*); *j*, nerves ending in loops; *k*, nerves ending in free ends; *l*, capillary plexus of vessels.

B. *a*, Two collateral nerve branches from the palmar surface of the index finger; *b*, Pacinian or touch corpuscles attached to said nerves, natural size.

C. Pacinian corpuscles magnified 100 times. *a*, Nerve with sheath (*b*); *c*, free end of nerve surrounded by fluid; *d*, capsule.

FIG. 2.—A. Papilla treated with acetic acid. *a*, Cortical layer with cells and fine elastic filaments; *b*, tactile corpuscle with transverse nuclei; *c*, entering nerve with neurilemma or perineurium; *d*, nerve fibres winding round the corpuscle (after Kölliker).

B. Magnified view of a sweat-gland with its duct. *a*, The gland surrounded by vesicles of adipose tissue; *b*, the duct passing through the corium; *c*, its continuation through the lower, and *d*, through the upper part of the epidermis (after Wagner).

FIG. 3.—A. Three nerve end bulbs from the human conjunctiva, treated with acetic acid. *a*, An oval-shaped figure with the termination of the nerve distinct; *b*, with one nerve fibre and fat granules in the core; *c*, with two nerve fibres forming coils within (after Ludden).

B. End bulb in papillæ magnified, treated with acetic acid. *a*, *b*, End bulbs.

C. Ditto. *a*, End bulb; *b*, *b*, capillaries.

D. Ditto from the tongue. *a*, Papillæ; *b*, end bulbs; *c*, *c*, nerves (after Kölliker).

FIG. 4.—Nerve fibres ending in taste-bud of rabbit (after Retzius).

FIG. 5.—Tactile corpuscle; specimen prepared in chromic acid. A, Vascular; B, nervous papilla; C, blood-vessel; D, medullated nerve fibre, enclosed in a thick nucleated sheath; E, tactile corpuscle; F, transversely divided medullated nerve fibres (after Biesiadecki).

FIG. 6.—Tactile corpuscles from the (edge of the) tongue of the sparrow. A, B, C, Medullated nerve filaments supplying four tactile corpuscles. One filament divides into two branches; and one of them is traced to near the extremity of the corresponding corpuscle, where it ends in a cell-like expansion (after Ihlder).

FIG. 7.—Terminal corpuscle of sensitive nerve; from the conjunctiva of the calf (after Frey).

PLATE CXXXVII

Plate cxxxvii. illustrates the relation subsisting between a large variety of nerve end and other bulbs.

FIG. 1.—A. *a*, Nucleated capsule; *b*, core; *c*, entering nerve fibre branching and its two divisions passing to terminate in the core at *d*.

B. End bulb treated with osmic acid, showing the core of the cells better than A. *a*, Entering nerve fibre; *b*, nucleated capsule; *c*, *c*, portions of the nerve fibre within the end bulb; *d*, cells of the core.

C. Ramification of nerve fibres in the mucous membrane, and their termination in end bulbs, as seen with a lens.

D. End bulb of the human conjunctiva, treated with 3 per cent. acetic acid and 1 per cent. osmic acid, $\frac{500}{1}$ (W. Krause).

PLATE CXXXV

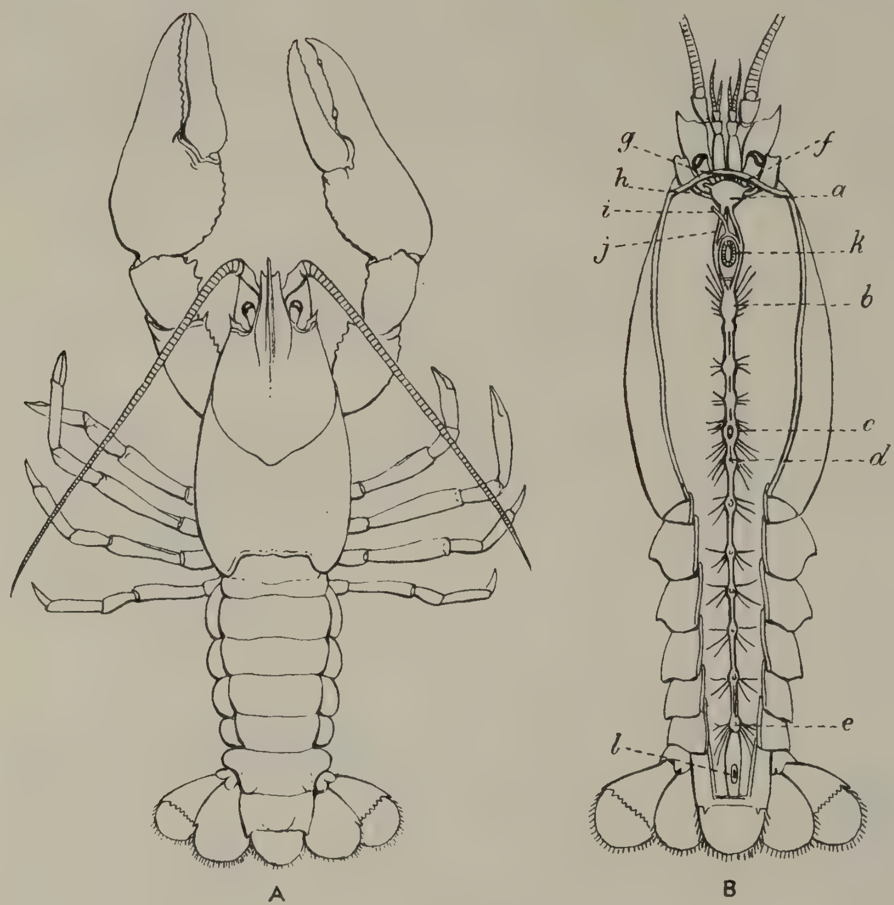
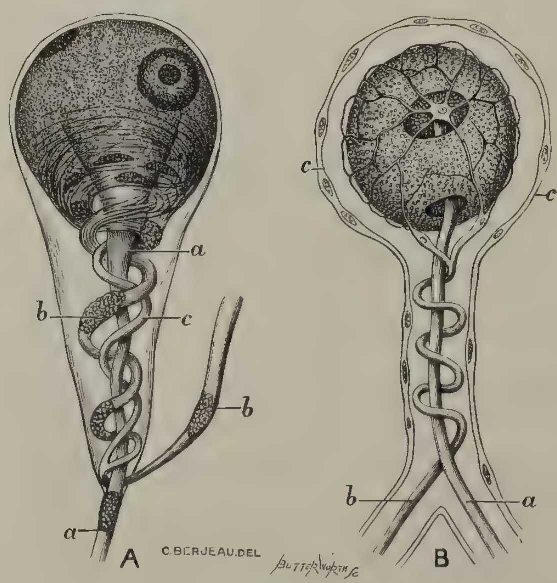


FIG. 1.

FIG. 3.

FIG. 2.



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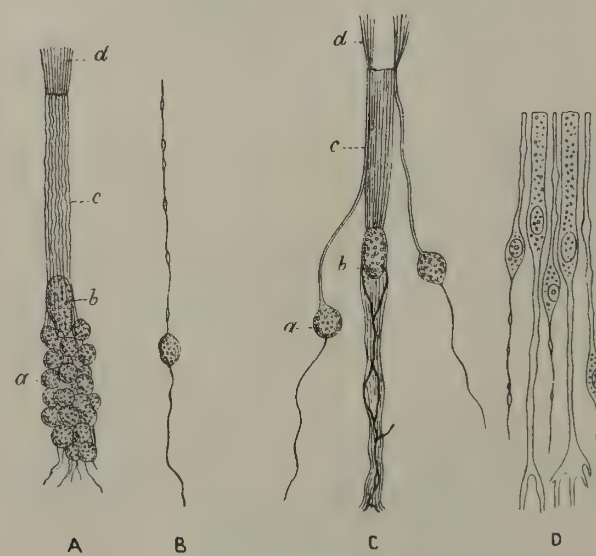


FIG. 5.

PLATE CXXXVI

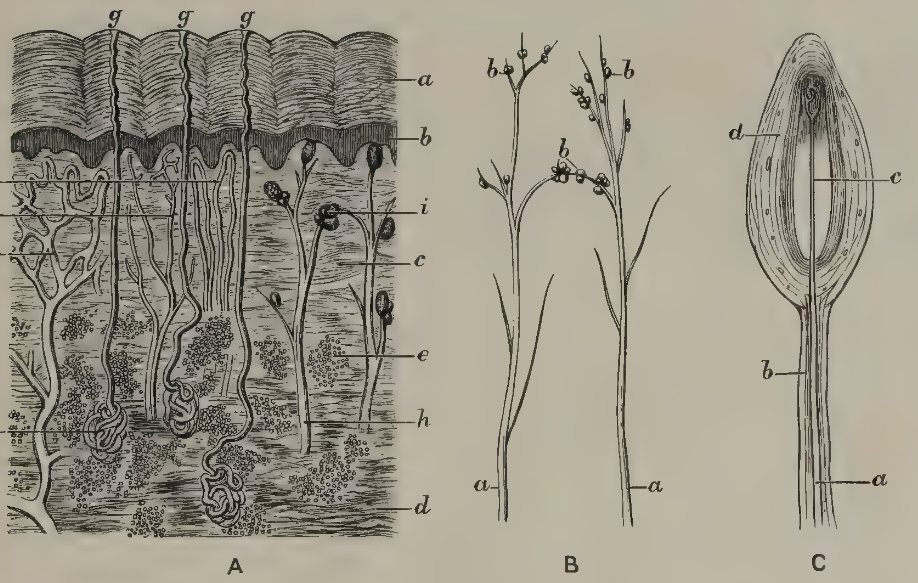
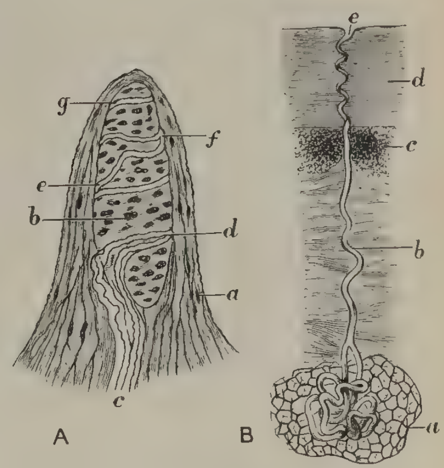


Fig. 1



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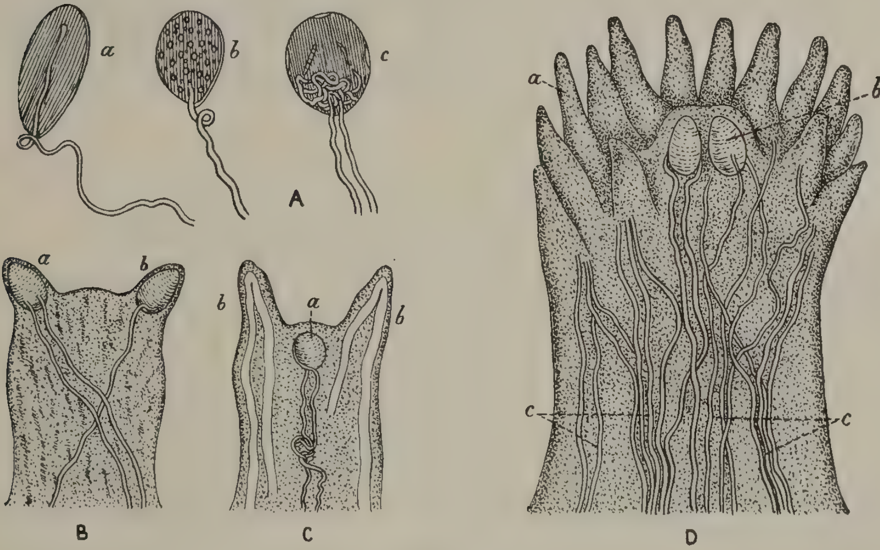


Fig. 3.

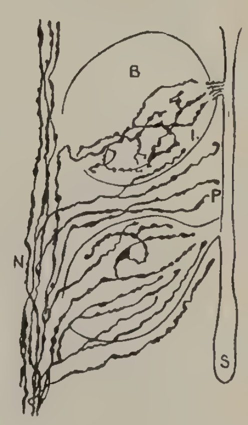


Fig. 4.

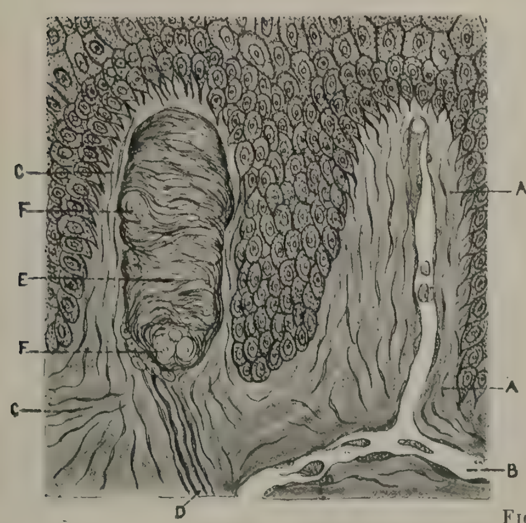


Fig. 5.

Fig. 6.

Fig. 7.

PLATE CXXXVII (*continued*)

E. Articular corpuscle from phalangeal joint in man. Acetic acid preparation (W. Krause), $\frac{300}{1}$. *a*, Two medullated nerve fibres entering the corpuscle.

F. Genital corpuscles from the human clitoris (W. Krause).

G, H. Genital corpuscles from the clitoris of the rabbit (Izquierds).

I. Cylindrical end bulbs from the conjunctiva of the calf (Merkel). In optical longitudinal section. *a*, Entering nerve; *b*, nucleated capsule.

J. Tactile corpuscle within a papilla of the skin of the hand, stained with chloride of gold (Ranvier). *a*, Two nerve fibres passing to the corpuscle; *b*, *b*, terminal varicose ramifications of the axis-cylinder within the corpuscle.

K. Motor end organ of a lizard. Gold preparation (Kühne). *a*, Nerve fibre; *b*, terminal ramification of axis-cylinder; *c*, clear substance surrounding the ramification (matrix); *d*, granular bed or sole of end organ.

L. Cross section of muscular fibre and end organ of lizard. Gold preparation (Kühne). *a*, Terminal ramification of axis-cylinder; *b*, matrix; *c*, nucleus of bed; *d*, nucleus of telolemma.

M. Motor end organ of human muscle. *a*, Medullated nerve fibre; *b*, terminal ramification of axis-cylinder.

Fig. 2.—Diagram of the connections of cells and fibres in the olfactory bulb. OLF.C., Cells of the olfactory mucous membrane; OLF.N., lowest layer of the bulb, composed of the olfactory nerve fibres, which are prolonged from the olfactory cells; GL., olfactory glomeruli, containing arborisations of the olfactory nerve fibres and of the dendrites of the mitral cells; MC., mitral cells; A, A, A, A, their axis-cylinder processes passing towards the nerve fibre layer, N.TR., of the bulb to become continuous with fibres of the olfactory tract—these axis-cylinder processes are seen to give off collaterals, some of which pass again into the lower layers of the bulb; N′, a nerve fibre from the olfactory tract ramifying in the grey matter of the bulb (after E. A. S.).

Figs. 3, 4, and 5.—Diagrams showing the mode of termination of sensory nerve fibres in the auditory, gustatory, and tactile structures of vertebrata (after G. Retzius).

Fig. 6.—Vertical section of a foliate papilla of the rabbit, passing across the folia. P, Central lamina of folium; V, vein; P′, lateral lamina of folium; G, taste-bud; N, sections of nerve-bundles; G, serous gland (after Ranvier).

Fig. 7.—Section through one of the taste-buds of the papilla foliata of the rabbit. Highly magnified. P, Gustatory pore; S, gustatory cell; R, sustentacular cell; M, leucocyte containing granules; E, superficial epithelium cells; N, nerve fibres (after Ranvier).

Fig. 8.—Vertical section of circumvallate papilla, from the calf. A, Papilla; B, vellum; N, bundles of nerve fibres entering papilla; D, duct of a serous gland opening into fossa around papilla (after Engelmann).

PLATE CXXXVIII

Plate cxxxviii. shows nerves of sensibility and of taste and smell.

Fig. 1.—Gustatory cells and bulbs.

A. Isolated gustatory bulb, from the lateral gustatory organ of the rabbit, ×600.

B. Isolated investing cells, from the gustatory bulbs of the rabbit, ×600.

C. Isolated gustatory cells, from the lateral organ of the rabbit, ×600.

D. An investing and two gustatory cells, isolated but still in connection with one another.

E. Termination of the gustatory nerves of the frog. Ramification of a nerve fibre in the nerve cushion, from a specimen prepared in glycerine. Group of two goblet-cells, one columnar, and two forked cells, from a specimen prepared in chromic acid and glycerine, ×600.

F. Isolated fork cells from the frog (*Rana temporaria*), ×600.

G. Upper half of the epithelial framework of the gustatory bulbs. Four cavities from which the bulbs have fallen out are here seen from the side of the mucous membrane. In the centre of the bottom of each is the gustatory pore. The specimen was taken from the lateral gustatory organ of the rabbit, ×450.

H. A gustatory bulb exposed in consequence of the detachment of the upper half of the epithelial framework, seen from above. From the lateral gustatory organ of the rabbit, ×450 (from Stricker, after Engelmann).

Fig. 2.—Papillæ from the skin of the hand, freed from the cuticle and exhibiting the tactile corpuscles.

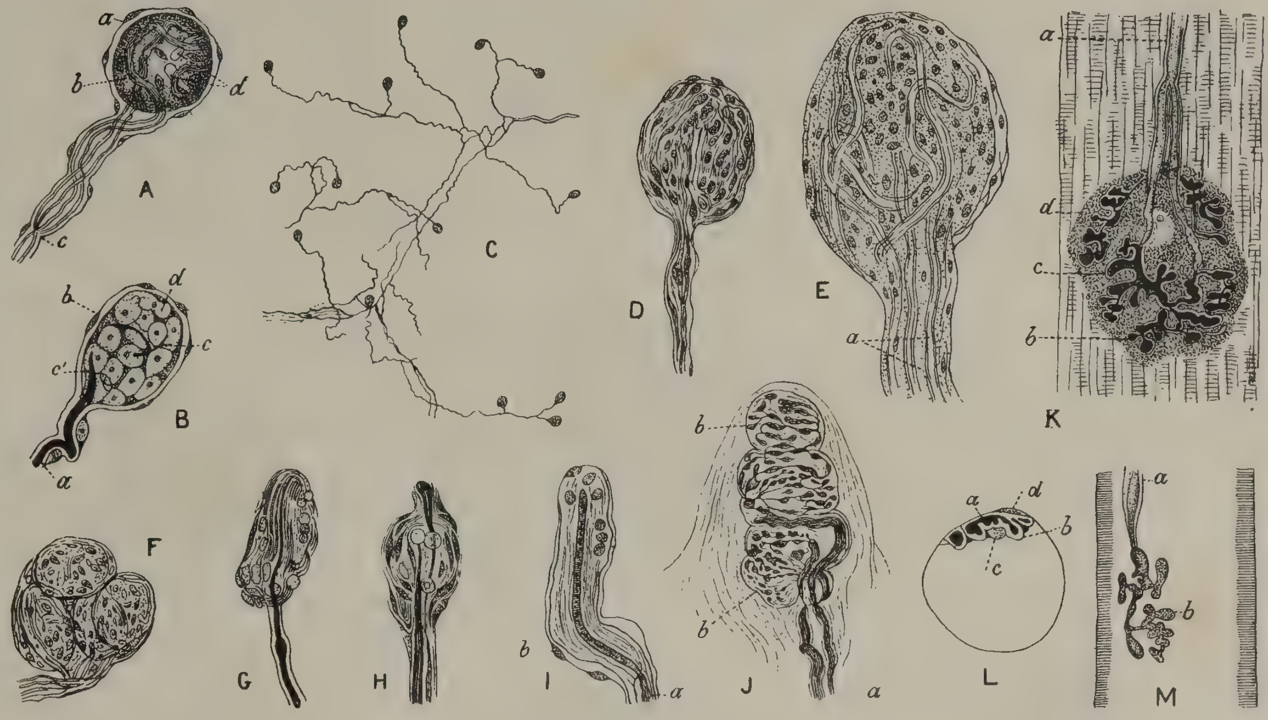
A. Papillæ treated with acetic acid. *a*, Cortical layer with cells and fine elastic filaments; *b*, tactile corpuscle with transverse nuclei, entering nerve with neurilemma or perineurium; *d*, *e*, *f*, *g*, nerve fibres winding round the corpuscle.

Fig. 3.—The mouth widely open to show the tongue and palate. *Uv*, The uvula; *T.n*, the tonsil between the anterior and posterior pillars of the fauces; *C.p*, circumvallate papillæ; *F.p*, fungiform papillæ. The minute filiform papillæ cover the interspaces between these. On the right side the tongue is partially dissected to show the course of the filaments of the glosso-pharyngeal nerve *VIII*; *V*, lingual branch of fifth pair (Huxley).

Fig. 4.—A section of the mouth and nose, taken vertically a little to the left of the middle line. *a*, The vertebral column; *b*, the gullet; *c*, the windpipe; *d*, the thyroid cartilage of the larynx; *e*, the epiglottis; *f*, the uvula; *g*, the opening of the left Eustachian tube; *h*, the opening of the left lachrymal duct; *i*, the hyoid bone; *k*, the tongue; *l*, the hard palate; *m*, *n*, the base of the skull; *o*, *p*, *q*, the superior, middle, and inferior turbinal bones. The letters *g*, *f*, *e* are placed in the pharynx (Huxley).

Figs. 5 and 6.—Nerves of the external and internal walls of the nasal fossa. *a*, *a*, Expansion of the olfactory or smelling nerve in the pituitary surface of the external and internal walls of one of the nasal fossæ; *b*, *b*, ethmoidal sprig of the nasal ramification of the ophthalmic branch of Willis; *c*, *d*, external and internal spheno-palatine nerves, both arising from the spheno-palatine ganglion (*e*); *f*, anterior palatine nerve, spreading to the pituitary membrane of the inferior turbinated bone; *g*, vidian nerve from which arises the naso-pharyngeal nerve to the mucous membrane of the posterior and superior portion of the nasal fossa and the Eustachian tube (from Hirschfeld and Léveillé).

PLATE CXXXVII



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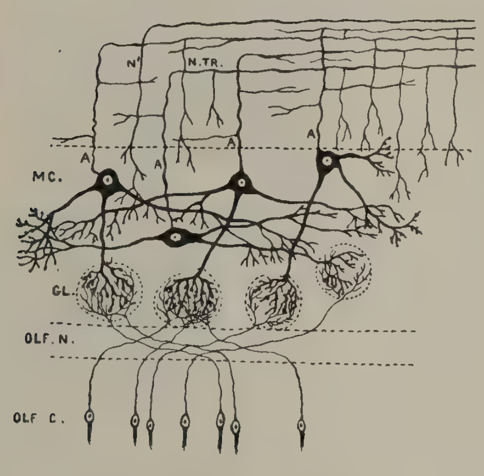

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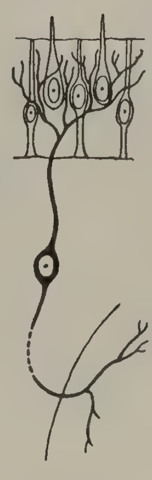

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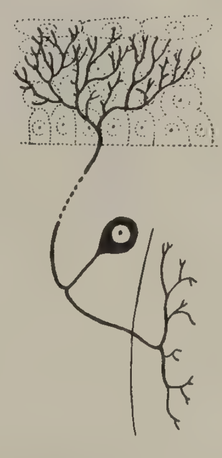

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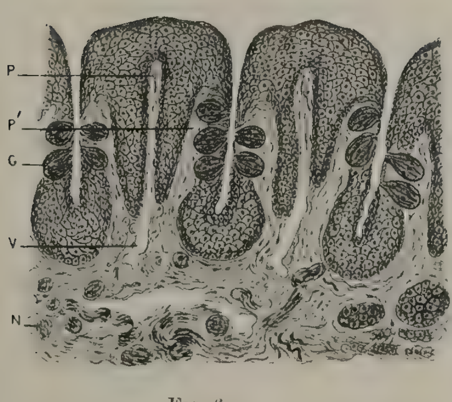

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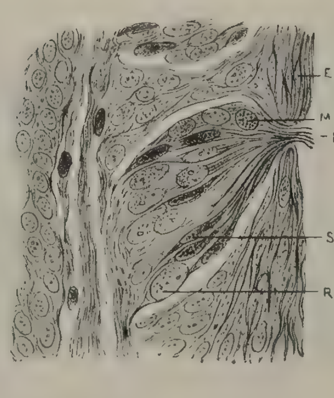

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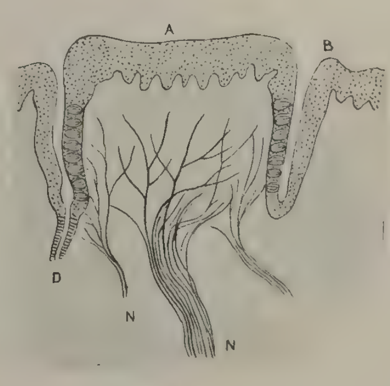
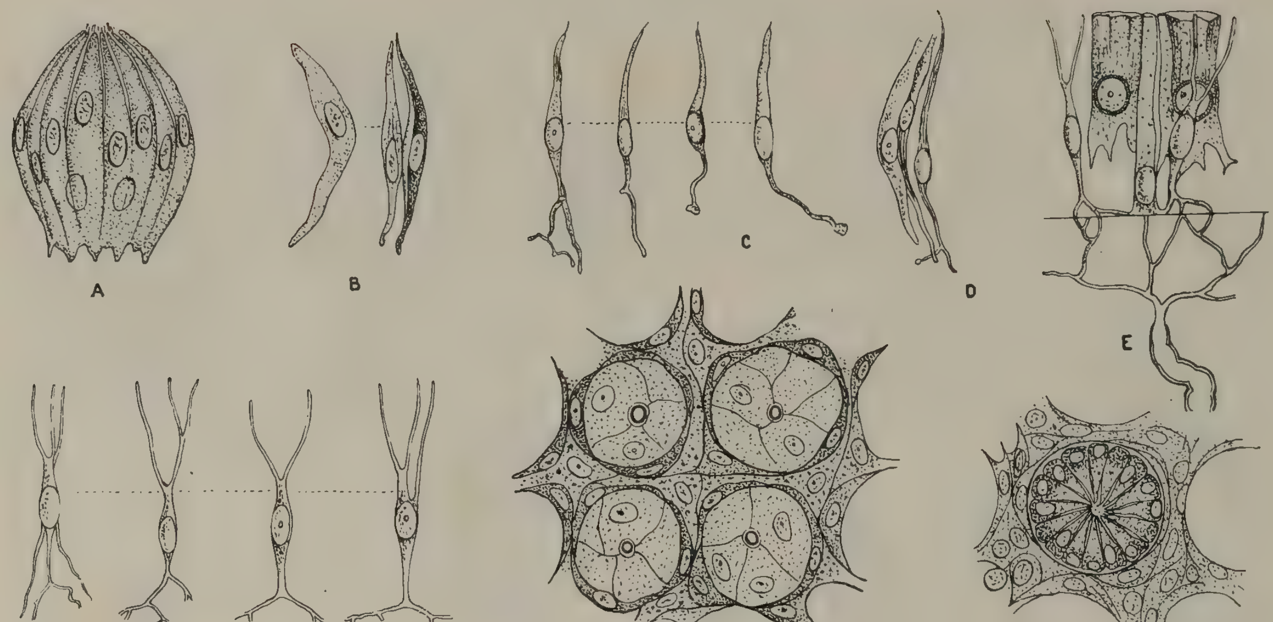


Fig. 8.

PLATE CXXXVIII



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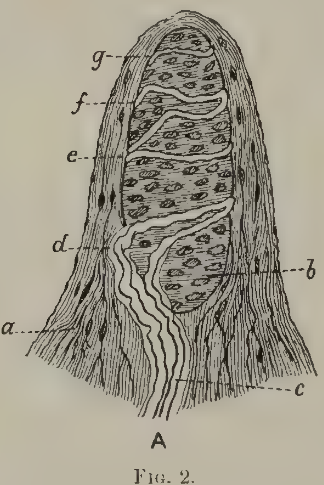

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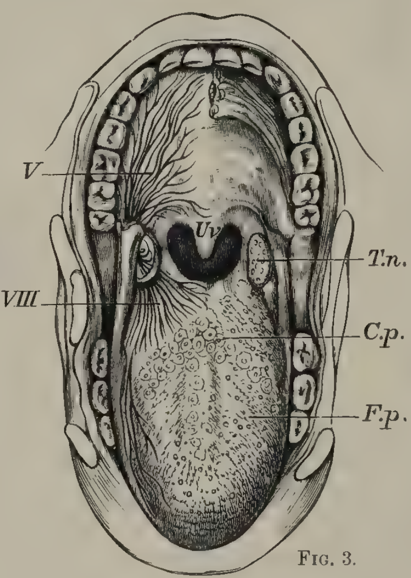

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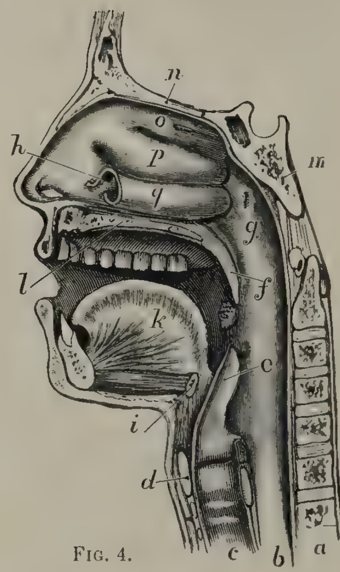

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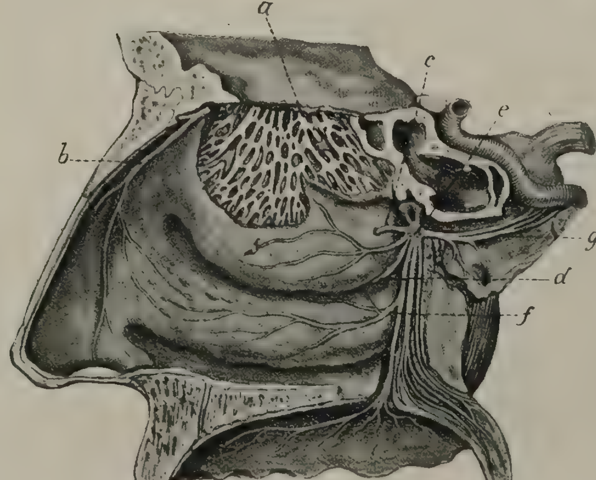

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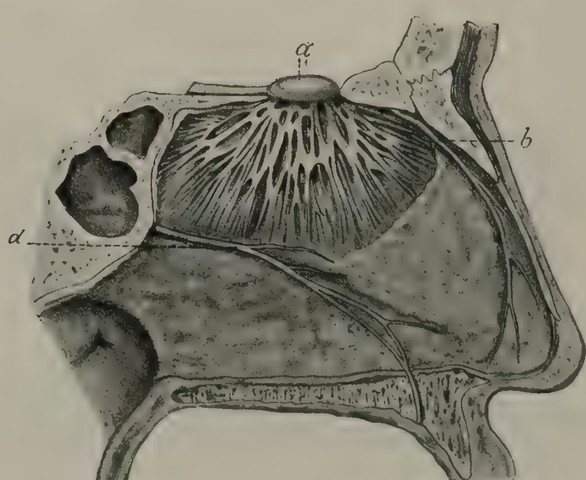


Fig. 6

PLATE CXXXIX

Plate cxxxix. illustrates the intimate relation which subsists between the organs of taste and smell. Shows a transverse section of the superior, middle, and inferior turbinated bones, &c., in the human nose ; shows also longitudinal section of the human ear and the labyrinth or internal ear.

FIG. 1.—Transverse section of turbinated or scroll bones of human skull (after Hirschfeld and Léveillé). The middle (*a*, *b*) and inferior (*c*, *d*) turbinated bones are distinctly spiral in their nature, the right ones (*a*, *c*) forming right-handed and the left ones left-handed spirals.

FIG. 2.—Human auditory apparatus. *a*, *a*, External or outer ear (pinna and lobe) ; *b*, funnel-shaped portion of external ear (meatus externus) ; *c*, membrana tympani or drum of ear ; *d*, ossicles (incus, stapes, and malleus) of middle ear ; *e*, Eustachian tube ; *f*, membrane of the fenestra ovalis ; *g*, vestibule or entrance to inner ear (labyrinth) ; *h*, cochlea of inner ear ; *i*, semicircular canals of inner ear (after Dalton).

FIG. 3.—A. Cochlea of ear laid open. *a*, *a'*, Osseous wall ; *b*, *b'*, lamina spiralis ; *c*, strands of cochlear nerve folding over at *d*, *d'* (after Hirschfeld and Léveillé).

FIG. 4.—A, B. Laminæ of cochlea of internal ear exposed (after Rüdinger).

FIG. 5.—Bony labyrinth of right internal ear of child. *a*, Cochlea. The semicircular canals are seen at the left of the figure (after Rüdinger).

FIG. 6.—B. Osseous labyrinth of left internal ear seen from without. *a*, Cochlea ; *b*, semicircular canals (after Hirschfeld and Léveillé).

FIG. 7.—Diagram of the mode of termination of the auditory nerve. *a*, Wall of ampulla ; *b*, structureless basement membrane ; *c*, doubly contoured nerve fibre ; *d*, axis cylinder traversing the basement membrane ; *e*, plexiform union of fine nerve fibres with interspersed nuclei ; *f*, fusiform cells with nucleus and dark fibre in their interior ; *g*, supporting cells ; *h*, auditory hairs (after Rüdinger).

FIG. 8.—View of the cavity of the tympanum opened from above. Magnified four times. *a*, Head of the malleus ; *b*, spina tympanica anterior ; *c*, anterior ligament of the malleus ; *d*, external ligament of the malleus ; *e*, gap between the two ligaments leading to the membrana flaccida and notch of Rivinus ; *f*, body of the incus ; *g*, posterior ligament of the incus ; *h*, processus orbicularis of the incus seen in the depth of the cavity, articulated with the head of the stapes (*i*) ; *i*, tendon of the stapedius muscle emerging from the pyramid ; *j*, thickened edge of a flattened band of ligamentous fibres which lies in the fold of the mucous membrane (*k*) and assists in fixing the malleus ; *l*, superior ligament of the malleus cut short ; *m*, tendon of the tensor tympani, emerging from the conical end of its canal (after Schäfer).

FIG. 9.—View of the left membrana tympani and auditory ossicles from the inner side, and somewhat from above. *a*, Malleus ; *b*, incus ; *c*, stapes ; *d*, pyramid from which the tendon of the stapedius muscle is seen emerging ; *e*, tendon of the tensor tympani cut short near its insertion ; *f*, anterior ligament of the malleus—the processus gracilis is concealed by the lower fibres of this ligament ; *g*, superior ligament of the malleus ; *h*, ligament of the incus ; *i*, chorda tympani nerve passing across the outer wall of the tympanum (after Schäfer).

PLATE CXL

Plate cxl. illustrates the various parts entering into the minute anatomy of the internal ear.

FIG. 1.—Tympanal wall of the ductus cochlearis of the dog. Surface view from the vestibular scala, after removal of the membrane of Reissner, magnified 300 diameters. I, Zona denticulata of Corti ; II, zona pectinata of Todd and Bowman ; 1, habenula sulcata of Corti ; 2, habenula denticulata of Corti ; 3, habenula perforata of Kölliker ; III, organ of Corti ; *a*, part of the lamina spiralis ossea, destitute of epithelium ; *b* and *c*, periosteal blood-vessels ; *d*, line of attachment of the membrane of Reissner ; *e* and *e'*, epithelium of the crista spiralis ; *f*, auditory teeth with the interdental furrows ; *g*, *g'*, large-celled (swollen) epithelium of the sulcus spiralis internus, partly glimmering through the auditory teeth, removed in the left half of the preparation ; *h*, foramina for the nerves ; *i*, internal hair cells ; *l*, internal pillars ; *m*, *n*, their capitate extremities ; *o*, external pillars ; *p*, lamina reticularis ; *q*, a few mutilated external hair cells ; *r*, external epithelium of the ductus cochlearis, removed at *s*, in order to bring into view the bases of the external hair cells (after Waldeyer).

FIG. 2.—Internal hair cells of the organ of Corti. *a*, Cuticula ; *b*, internal hair cells ; *c*, granule layer ; *d*, perforating nerve fibre ; *e*, similar fibre becoming fused with hair cell ; *f*, nerve fasciculi (oblique section) ; *g*, transversely divided blood-vessel (after Waldeyer).

FIG. 3.—Section of epithelium of ampulla of *Lacerta viridis*. A, Auditory hairs ; B, hair cells ; C, nuclei of supporting cells ; D, medullated nerve fibres (after Retzius).

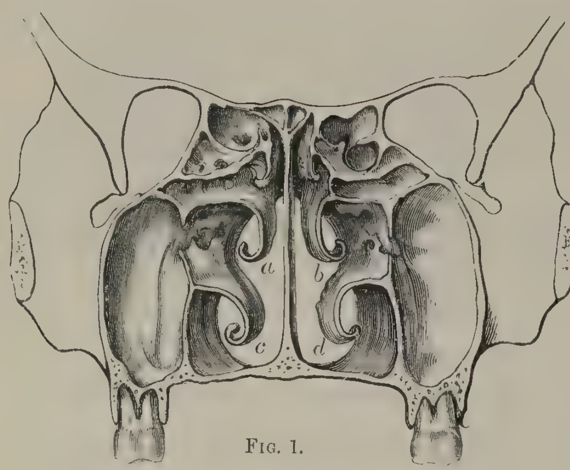
FIG. 4.—View of a small part of the organ of Corti of the human cochlea from above, showing the lamina reticularis. Much magnified. A, Inner hair cells, the hairlets being seen in section ; B, heads of inner rods ; C, heads of outer rods ; D, "olecranon" processes of inner rods ; F, phalangeal processes of outer rods ; G 1, G 2, G 3, first, second, and third series of phalanges ; E 1, E 2, E 3, E 4, first, second, third, and fourth series of outer hair-cells ; H, cells of Hensen (after Retzius).

FIG. 5.—Semi-diagrammatic view of part of the basilar membrane and tunnel of Corti of the rabbit, from above and the side. Much magnified. *a*, Limbus ; *b*, labium vestibulare or crest of limbus with tooth-like projections ; *c*, *c'*, basilar membrane ; *d*, spiral lamina with (*e*) perforations for transmission of nerve fibres ; *f*, fifteen of the inner rods of Corti ; *g*, their flattened heads seen from above ; *h*, nine outer rods of Corti, their heads with the phalangeal processes extending outward from them and forming, with the two rows of phalanges, the lamina reticularis, *i* (after Schäfer).

FIG. 6.—Transverse section of the ampulla of the ear of the pike. *a*, Roof of the ampulla ; *b*, floor of the ampulla with the auditory nerves, *c*, *c* ; *d*, nerve epithelium ; *e*, auditory hairs ; *f*, planum semilunare ; *g*, pavement epithelium (after Rüdinger).

FIG. 7.—Diagram of the mode of termination of the auditory nerve. *a*, Wall of the ampulla ; *b*, structureless basement membrane ; *c*, doubly contoured nerve fibre ; *d*, axis-cylinder traversing the basement membrane ; *e*, plexiform union of fine nerve fibres with interspersed nuclei ; *f*, fusiform cells with nucleus and dark fibre in their interior ; *g*, supporting cells ; *h*, auditory hairs (after Rüdinger).

PLATE CXXXIX



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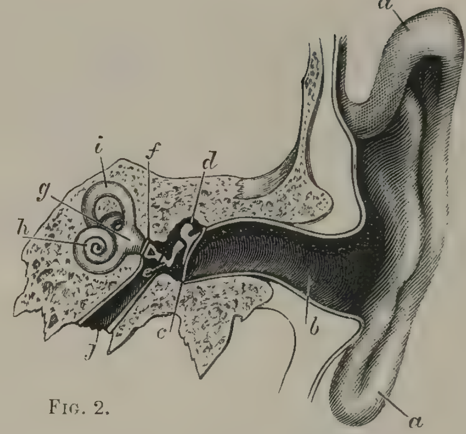

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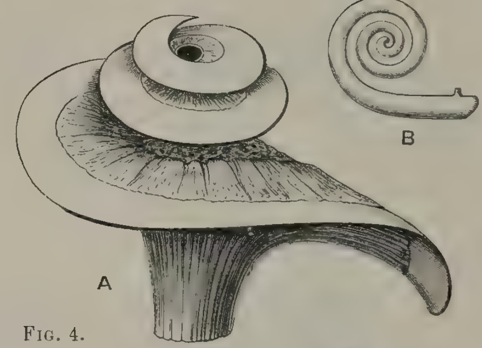

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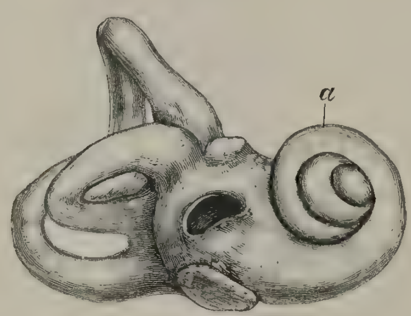

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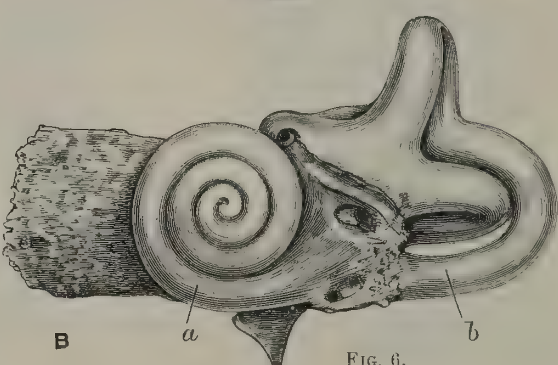

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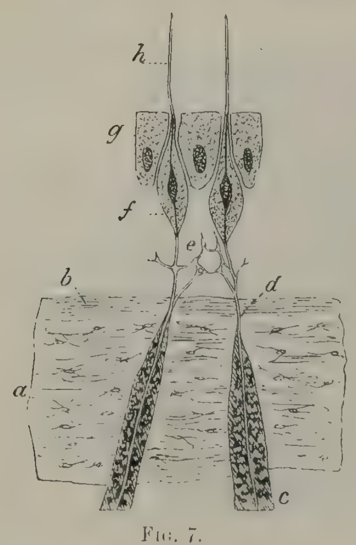

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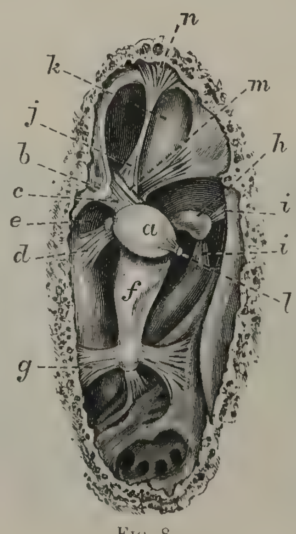

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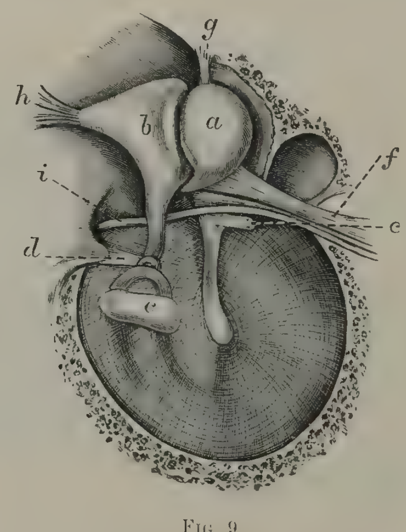
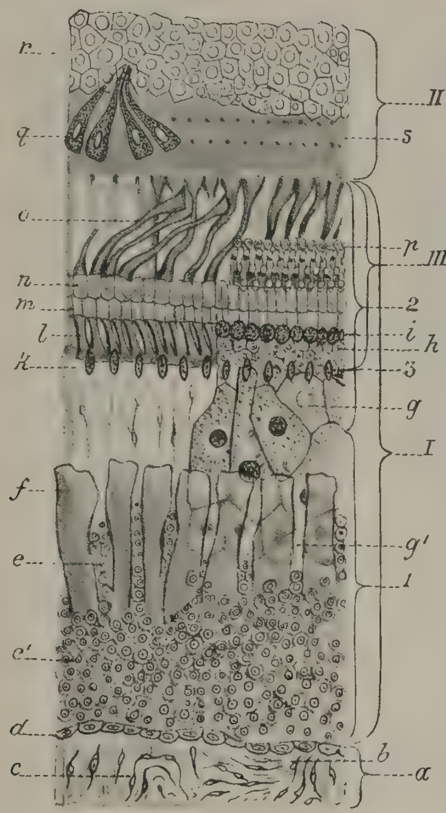


Fig. 9.

PLATE CXL



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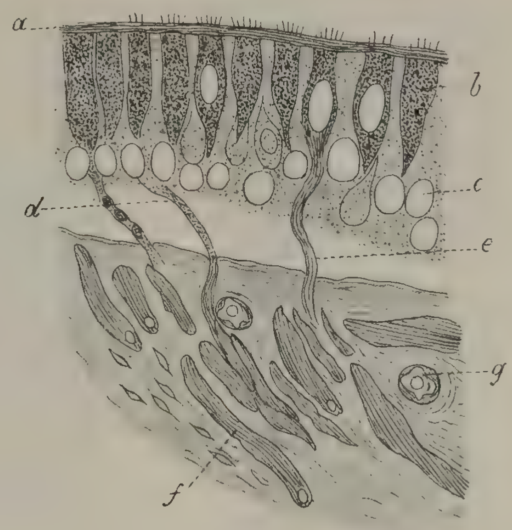

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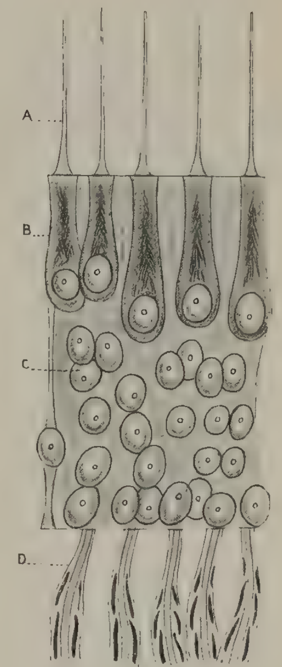

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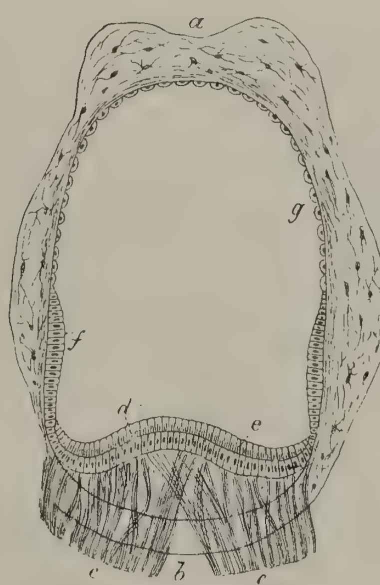

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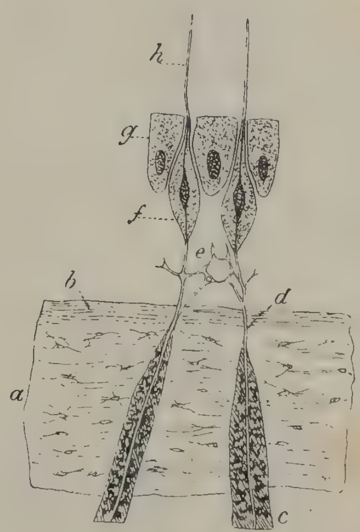

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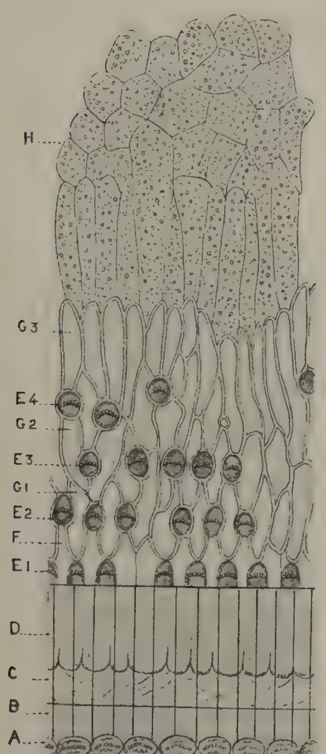

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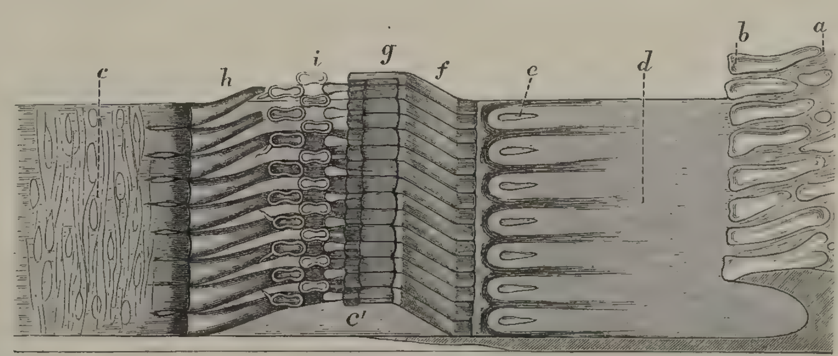

Fig. 5.

PLATE CXLI

Plate cxli. illustrates the parts connected with vision. The figures show an analogy between the structures concerned in tasting, smelling, hearing, and seeing. They further show that the sense organs are differentiations and expansions of the peripheral nerves. As a matter of fact all the sense organs are modifications of the nerve endings in the integument: thus the eye may not inaptly be regarded as a modification of the Pacinian body.[1] Similar remarks may be made of the touch and other corpuscles found in the tongue, nostrils, eyes, &c. The organs of hearing and seeing are characterised by their power to receive and give off vibrations, which they do by the aid of elongated delicate structures free to move in space.

Fig. 1.—A front view of the eye dissected to show (*Orb.*) the orbicular muscle of the eyelids, the pulley and insertion of the superior oblique (*S.Ob.*); and the inferior oblique (*Inf.Ob.*); *L.G.*, the lachrymal gland (after Huxley).

Fig. 2.—The muscles of the eyeball viewed from above. *S.R.*, The superior rectus; *E.R.*, the external rectus; *S.Ob.*, the superior oblique; *Ch*, the chiasma of the optic nerves (II); I, the third nerve, which supplies all the muscles except the superior oblique and the external rectus (after Huxley).

Fig. 3.—Simple papilla with four nerve fibres. *a*, Cortical layer; *b*, tactile corpuscles; *c*, entering nerves; *d*, *e*, nerve loops (after Kölliker).

Fig. 4.—Papilla seen from above so as to appear as a cross section. *a*, Cortical layer; *b*, sheath of the tactile corpuscle containing nuclei; *c*, core (after Kölliker).

Fig. 5.—Pacinian corpuscles. A. Nerve axis (axis cylinder of Purkinje); B, nerve sheath; C, central sensitive portion of sensory nerve; D, fluid in contact with said portion; E, concentric layer of fibrous tissue forming body of corpuscle, A (*Enc. Anat. Physiol.*).

Fig. 6.—A. Three nerve end bulbs from the human conjunctiva, treated with acetic acid. *a*, Of an oval figure, the termination of nerve distinct; *b*, with one nerve fibre and fat granules in the core; *c*, with two nerve fibres forming coils within (after drawing by Lüdden).

Fig. 7.—B, C. End bulbs in papillæ magnified, treated with acetic acid. B. *a*, *b*, end bulbs; C. *a*, end bulb; *b*, *b*, capillaries (after drawing by Lüdden).

Fig. 8.—Isolated gustatory bulb from the lateral gustatory organ of the rabbit. Magnified 600 diameters (after Engelmann).

Fig. 9.—Right adult human eye, divided horizontally through the middle. A, B, Equator; C, D, visual axis; E, E, conjunctiva; F, cornea; G, aqueous humour; H, iris; I, crystalline lens; J, vitreous humour; K, pars ciliaris retinæ; L, ligamentum suspensorium lentis; M, musculus ciliaris; N, retina; O, choroidea; P, sclera; Q, arteria centralis retinæ; R, optic nerve; S, dural sheath (after Quain).

Fig. 10.—Section of epithelium of ampulla of *Lacerta viridis*. A, Auditory hairs; B, hair cells; C, nuclei of supporting cells; D, medullated nerve fibres (after Retzius).

Fig. 11.—General view of the layers of the retina of man, ×400. *a*, Membrana limitans interna; *b*, optic fibre layer; *c*, ganglion cell layer; *d*, internal granulated (molecular) layer; *e*, internal granule layer; *f*, external granulated (intergranule) layer; *g*, external granule layer, including the external fibre layer, which is present in certain parts of the retina; *h*, membrana limitans externa; *i*, layer of rods and cones; *j*, pigment layer (after Max Schultze).

Fig. 12.—View of the posterior part of the fundus of the human retina. *f*, External granulated layer; *g*, external granule layer; *h*, limitans externa; *i*, rods and cones, the external segments of which are sharply differentiated from the internal cylinders, ×800. The supporting fibres of the connective tissue are omitted in this figure (after Max Schultze).

PLATE CXLII

Plate cxlii. illustrates the shape, position, and density of the crystalline lens of the eye in relation to the accommodation, &c., of vision. Shows how the shape of the lens assists in focussing and determining the distance between the seeing object and the object seen.

"*The function of the crystalline lens is to produce distinct perception of form and outline.* For if the eye consisted merely of a sensitive retina, covered with transparent integument, though the impressions of light would be received by such a retina they could not give any idea of the form of particular objects, but could only produce the sensation of a confused luminosity." This and other points have been made very clear by Professor John C. Dalton,[2] as shown at Fig. 1, "where the arrow *a*, *b* represents the luminous object, and the vertical dotted line at the right of the diagram represents the retina. Rays, of course, will diverge from every point of the object in every direction, and will thus reach every part of the retina. The different parts of the retina, consequently, 1, 2, 3, 4, will each receive rays coming both from the point of the arrow, *a*, and from its butt, *b*. There will therefore be no distinction, upon the retina, between the different parts of the object, and no definite perception of its outline. But if, between the object and the retina, there be inserted a double convex refracting lens, with the proper curvatures and density, as in Fig. 2, the effect will be different. For then all the rays emanating

[1] The parts which the eye and the Pacinian body have in common can readily be traced. (1) They are bounded by a fibrous membrane; (2) they each contain a fluid; (3) they admit of change of shape; (4) they have a central nerve core or axis; (5) they furnish sensitive receiving surfaces and deal with sensory impressions.

[2] "A Treatise on Human Physiology," by John C. Dalton, M.D., p. 509.

PLATE CXLI

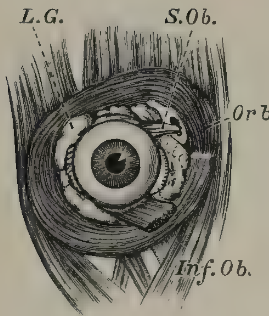

FIG. 1.

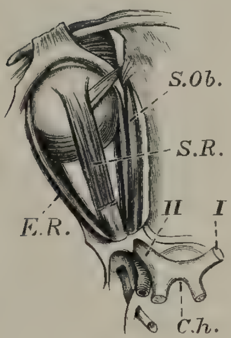

FIG. 2.

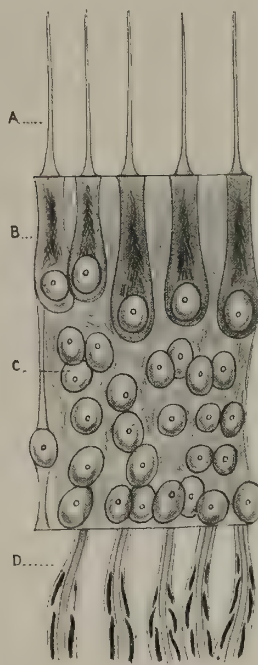

FIG. 10.

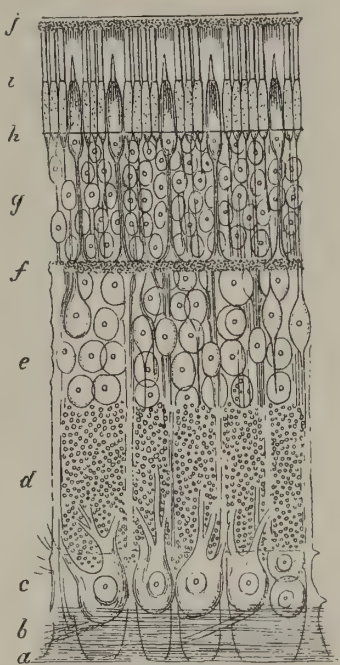

FIG. 11.

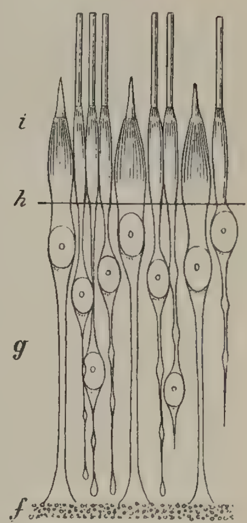

FIG. 12.

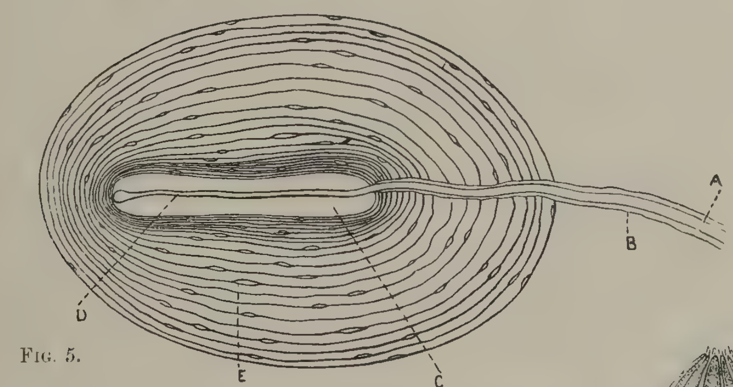

FIG. 5.

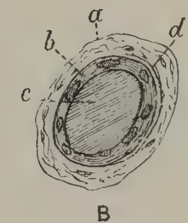

FIG. 4.

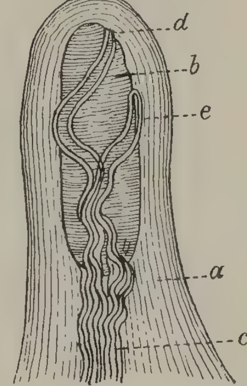

FIG. 3.

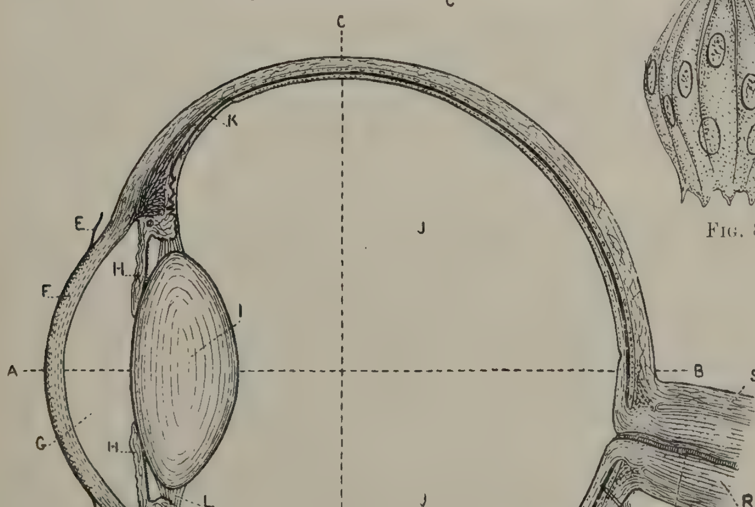

FIG. 9.

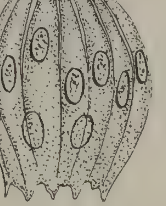

FIG. 8.

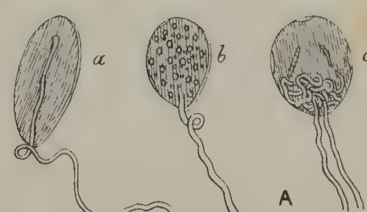

FIG. 6.

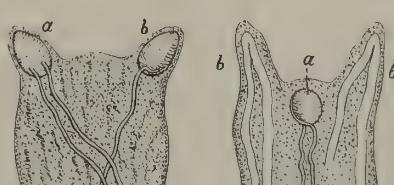

FIG. 7.

PLATE CXLII

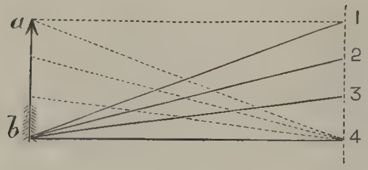

FIG. 1.

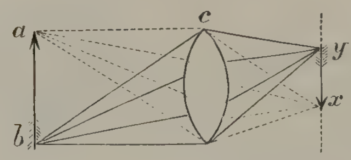

FIG. 2.

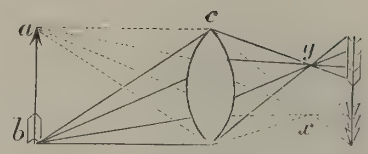

FIG. 3.

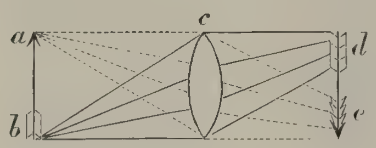

FIG. 4.

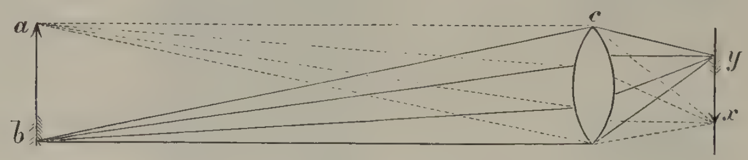

FIG. 5.

from *a* will be concentrated at *x*, and those emanating from *b* will be concentrated at *y*. Thus the retina will receive the impression of the point of the arrow separate from that of the butt; and all parts of the object, in like manner, will be distinctly and accurately perceived.

"This convergence of the rays of light is accomplished to a certain extent by the other transparent and refracting parts of the eyeball; but the lens is the most important of all in this respect, owing to its superior density and the double convexity of its figure. The distinctness of vision, therefore, depends upon the action of the lens in converging all the rays of light emanating from a given point to an accurate focus *at the surface of the retina.* To accomplish this, the density of the lens, the curvature of its surfaces, and its distance from the retina, must all be accurately adapted to each other. For if the lens were too convex, and its refractive power excessive, or its distance from the retina too great, the rays would converge to a focus too soon, and would not reach the retina until after they had crossed each other and become partially dispersed as in Fig. 3. The visual impression, therefore, coming from any particular point in the object would not be concentrated and distinct, but diffused and dim, from being dispersed more or less over the retina, and interfering with the impressions coming from other parts. On the other hand, if the lens were either too flat, or placed too near the retina, as in Fig. 4, the rays would fail to come together at all, and would strike the retina separately, producing a confused image, as before. In both these cases, the immediate cause of the confusion of sight is the same, namely, that the rays coming from the same point of the object strike the retina at different points; but in the first instance, this is because the rays have actually converged, and then crossed; in the second, it is because they have only approached each other, but have never converged to a focus. . . .

"We can now see how these alterations produce the required changes in accommodation. When the eye is accommodated for distant vision, the lens assumes the form which is normal to it when in repose and unaffected by external agencies. Its curvatures are then such that rays coming from distant points, and having consequently but a slight divergence, are brought to a focus, behind the lens, exactly at the sensitive surface of the retina (Fig. 5)."

The forces generated by nerves and muscles are vital in their nature; the brain thinks, and the muscles perform work of various kinds. The brain becomes exhausted by intellectual labour, and the muscles by work, and both require to be rested and fed. Dead brain and dead muscle can achieve nothing. Intellectual and muscular work are the outcome of living structures duly nourished, exercised, and rested at intervals.

It is not doubted that the work performed by living muscle resembles, in its results, that performed by physical force, say that exerted by a steam-engine. The mode of production of the two forces is, however, entirely different. Similarly, the force produced by living brain substance cannot be identified with any known physical force. No physical force can, of itself, control, direct, and guide other forces. The directive force inhering in brain is a thing *per se;* the product of life, and the structures which life begets. The physicist and chemist cannot manufacture a living muscle capable of performing work; they can still less manufacture a living brain capable of thinking. The identity of muscle and brain force on the one hand, and physical force on the other, cannot be established so long as life is admitted to be necessary to the production of the former. The existence of electrical currents in dead muscle and nerve is no proof that electricity is the prime mover in living

muscle and brain. All that can be said is, that muscle and brain are primarily developed from inorganic materials, and share or participate, up to a point, in the forces which inhere in the said materials. The electric currents met with in nerves and muscles are due, there is reason to believe, to molecular changes occurring in their substance. Professor Emil du Bois-Reymond was of opinion that a muscular fibre is composed of electrical molecules which he designated peripolar molecules, each of which has an equatorial belt displaying positive electricity, and on either side two polar regions manifesting negative electricity.

Dr. C. B. Radcliffe promulgated a slightly different view. According to him a muscular fibre consists of two sets of electrical molecules: "the one set, in which positive electricity is external and negative internal, arranged round the outside of the fibre; the other set of molecules, in which the negative electricity is external and positive internal, being placed in the core of the fibre." Both theories tend to explain the fact that the current in the direction of the length of the muscle is positive, while that across it is negative.

That living structures can produce electricity is abundantly proved in the case of the electric fishes, among which may be mentioned the common skate (*Raia batis*), the raasch or thunder fish (*Malapterurus electricus*), the torpedo (*Torpedo marmorata*), and the electrical eel (*Gymnotus electricus*). The electric fishes, as is well known, manufacture electricity by the aid of a special electric organ in their bodies; the organ resembling a voltaic pile, in some case with one fluid, and in others with two fluids. The electricity so manufactured is discharged in self-defence and in securing prey.

"The electricity generated by the electric fishes has considerable tension, and is capable of developing the electric spark, of magnetising steel, of decomposing iodide of potassium, and of affecting a galvanometer."[1]

According to Humboldt, a full-grown, vigorous electric eel can discharge sufficient electricity to kill a horse. When the eel has once spent its electric energy it is harmless. It must manufacture a new supply before it can again attack. In this respect it resembles an ordinary dynamo-electric machine.

PROOFS THAT THE BRAIN IS THE ORGAN, APPARATUS, OR LABORATORY OF THE MIND

1. The brain rests eight hours or so (period of sleep) out of the twenty-four, and during that time the mind is a blank.

2. If anæsthetics be administered beyond a certain point consciousness is obliterated. Similar results follow a sudden and severe knock on the head, as in concussion.

3. The activity of the brain largely depends on the quantity of blood in the head.

4. The intellectual faculties are sluggish after a full meal. They are most active between meals. They are also more active during the day than during the night.

5. Alcohol, which acts on the nervous system and brain, completely upsets the mind if taken in immoderate quantities.

6. When the brain is overworked during the day, sleep at night is difficult or impossible. The brain apparatus is excited, and endless mental pictures, known as dreams, are formed.

7. Memory and association of ideas are the result of molecular brain changes.

8. Mesmerism is largely a physical condition.

9. If the brain be sliced away in a direction from above downwards, say in a pigeon, intelligence disappears in proportion as the cerebrum is removed.

10. In chronic insanity, where the mind is hopelessly deranged, the brain substance is diseased.

11. The child's brain is large but of poor quality, hence the rudimentary condition of the mind of the young individual.

12. The European brain is larger and of better quality than that of the savage. This explains the superior intelligence of the former as compared with the latter.

13. The brain can be trained and developed. It is not possible to train and develop what is immaterial.

14. In animals, intelligence is in keeping with the size and quality of the brain.

In 1873 I explained that the brain had inherent sensitive and motor nerves—that the special sense organs (tasting, smelling, seeing, and hearing organs) represented the sensory nerves proper outside the brain, but that there were others inside the brain cavity which sought the surface of the organ, but which had deteriorated from not being used, although they would still respond to certain forms of stimulation (galvanism, &c.). They could, under certain circumstances, be made to convey impressions to the nerve centres and ganglia of the brain to

[1] Faraday, "Experimental Researches in Electricity," ser. xv. Du Bois-Reymond, "Monatsber. des Berlin Akad.," 1861, p. 1105.

which they properly belonged. I further demonstrated that the nerve centres in turn operated on the motor cranial nerves, with the result that certain groups of muscles outside the brain cavity are set in motion. This, I held, explained the experiments of Fritz, Hitzig, Ferrier, and others with galvanism. Thus when a portion of the skull of a dog has its membranes removed to expose the brain, and the corresponding area is galvanised, the dog wags its tail. Under similar circumstances a rabbit moves its lips.

The existence of the largely disused and deteriorated sensitive nerves at the surface of the brain within the cranium explains why the area stimulated does not diffuse itself, but is confined to certain nerve centres and motor nerves and muscles. It also explains the low sensitiveness of the brain substance as a whole.

It is admitted that the cerebrum or brain proper is an expansion of the spinal cord, and that motor nerves are found in profusion especially at the base of the brain. But it is well known that the spinal cord has everywhere a complete sensitive set of nerves, a motor set. The sense organs only represent a small proportion of the sensory nerves of the brain, and the question arises, What has become of all the other sensory nerves which naturally belong to such a large mass of ganglionic nerve substance? They are, as I endeavoured to explain, not wholly obliterated, but merely dwarfed and atrophied because of disuse. This peculiar, and more or less abnormal, state of things is perpetuated by the conditions under which the brain works. The brain acts largely through its motor nerves; these, being kept continually employed and in activity, have not deteriorated, hence the marked difference between the sensory and motor nerves of the brain structurally and functionally.

In mental operations—thinking, judging, remembering, &c.—an effort or a series of efforts are put forth, and many are of opinion that before the effort can be made changes must occur in the molecular basis of the brain. Another view is that the effort precedes all change in the molecules and cells of the brain.

The molecular changes are consequent on the efforts, and cease when the efforts cease. The distinction here indicated raises the question as to whether the brain is self-acting or requires to be jogged into activity by extraneous stimulation. I hold that the brain is self-acting from the fact that it can and does rest as well as work.

That thinking and consciousness are in a great measure, if not wholly, due to molecular change occurring in the brain seems proved by this. If one be stunned by a fall or by a blow on the head, and the molecular balance of the brain be even temporarily disturbed, consciousness and the power of thinking both disappear. Pressure on the brain such as is produced by a blood clot or a depressed portion of skull brings about the same result. Softening of the brain caused by innutrition where the molecules are deteriorated leads to loss of memory, the power of judging and reasoning, and finally to idiocy. It is impossible to dissociate the manifestations of mind from molecular change in the brain substance. In this sense the brain is the actual organ of the mind. The freedom of the will is not prejudiced by any number of brain changes.

That the brain acts interruptedly or rhythmically at intervals seems proved by certain cases of disease. In epilepsy, for example, the sufferer is attacked at stated periods. He may have his fit every fortnight, every month, every two months, &c., but when the fit comes on the brain discharges nerve force (pent up, as it were) which results in unconsciousness and in violent muscular movements more or less definitely rhythmic in character. All kinds of convulsions are to be placed in the same category.

That nerve centres and nerve areas exist in the brain is placed beyond doubt by the researches of Fritz, Hitzig, Ferrier and several others. These centres, moreover, are connected with certain groups of muscles or muscular territories upon which they exert a direct and indirect influence. Within limits the same may be said of the spinal cord. The moot point concerns the motor nerves. How do these nerves act? Are there one or two sets, or can one motor nerve perform two functions? It appears to me that in the hollow viscera with sphincters, such as the stomach and bladder, there must be a double arrangement of muscles and a double arrangement of nerves to bring about the co-ordinated rhythmic movements which characterise their working.

In both cases the sphincters are thick and very powerful, and the walls of the viscera thin and comparatively very weak. So much is this the case that the viscera by their contractions cannot force by any possibility the passages of the sphincters. The sphincters must open spontaneously when the viscera contract. To meet the difficulty the muscles of the viscera and the muscles of the sphincters must each possess the power of opening and closing by vital independent movements, or the nerves which regulate the movements of the viscera and their sphincters—which, be it observed, are diametrically opposite movements—must be of two kinds, or have a cross arrangement whereby they cause the bodies of the viscera to close or contract at the same instant that they cause the sphincters of the viscera to open or relax. There seems to be no escape from this conclusion.

Of course one can understand that a motor nerve can discharge a double function, causing a muscle first to close or shorten and then to open or elongate; the one movement being virtually contained within the other. Muscular motion essentially consists of change of shape in the moving part.

The sarcous elements of a muscle, and a muscle itself, when they shorten in one direction elongate in an

opposite direction. If, however, a motor nerve caused a sarcous element or a muscle to change its original shape by one impulse, why should not the same nerve cause the same sarcous element or muscle to regain its original shape by another or second impulse ? In either case it is only a change of shape which is effected and required, and if the motor nerve can occasion a change of shape in one direction it should have no difficulty in causing a change of shape in another direction, the more especially if that be a return to the original shape.

To me this is very simple, because I believe that each sarcous element and each muscle is endowed with a double power, namely, a power of shortening and a power of elongating in the case of hollow muscles (see Plate lxxxiii., p. 320).

The matter becomes more difficult when the sarcous element and the muscle are accredited with only one power, namely, the power of shortening or contracting, and where elasticity or some counteracting force must be assumed as necessary for the elongation or relaxation, as it is termed.

The majority of physiologists of the present day refer the movements of muscles, both the voluntary and the involuntary, to the direct action of nerves. I am, on the contrary, of opinion that in the involuntary muscles proper (heart, stomach, alimentary canal, bladder, uterus, &c.), the rhythm inheres equally in the muscles and in the nerves ; whereas in the voluntary muscles proper it inheres largely in the nerves, and to a less extent in the muscles which have assumed rhythmic movements, as, for instance, the muscles of respiration and those which have been trained to perform quasi-rhythmic movements, as seen in locomotion, &c.

As examples of the position assigned to nerve action in respiration I may quote some authorities on the nerve supply to the larynx, lungs, diaphragm, and respiratory muscles generally.

According to Professor Austin Flint,[1] "The muscles which are concerned in producing the movements of the glottis are animated by the inferior laryngeal branches of the pneumogastric nerves. If these nerves be divided the movements of the glottis are arrested, and respiration is very considerably interfered with. This is particularly marked in young animals, in which the walls of the larynx are comparatively yielding, when the operation is frequently followed by immediate death from suffocation."

Professor Sir Michael Foster says : [2] "The rhythmic alternating of widening and of narrowing observed in laboured breathing is, through the activity of the bulbar nervous mechanism, brought about by the various muscles . . . the sphincter group being specially used for narrowing. . . . Both the continued patency and the rhythmic changes are carried out by means of the recurrent laryngeal nerves."

Sir Michael Foster here refers to two essentially different things as being produced by one and the same cause ; namely, the patency and the rhythmic changes in the larynx. This indicates that the patency and the action of the recurrent nerve are inherent and spontaneous, and are not dependent upon irritability.

The larynx is endowed with voluntary and involuntary rhythmic movements.

According to Sir Michael Foster, "When the larynx is used for the production of voice the recurrent laryngeals are brought into play. When both the recurrent laryngeal nerves are divided voice is lost. . . . Voice is for the most part an intentional and skilled act. . . . Hence we find an area in the motor region of the cerebral cortex devoted to phonation. . . . Stimulation of the area in question in the monkey or of the corresponding area in the dog leads to adduction of the chords and closure of the glottis, the resulting movement being bi-lateral . . . so far adduction only has been the experimental result of stimulation of the cortex in the monkey and the dog, an area for adduction having been found in the cat alone. . . . But stimulation of the cortex near the pure centre for phonation leads to an acceleration in the rhythm of and exaggeration of the laryngeal respiratory movements, as indeed of the respiratory movements as a whole : though the respiratory laryngeal movements are in the main worked by a bulbar mechanism, they can be influenced by cortical changes."

According to Professor Austin Flint,[1] "The contractions of the diaphragm are animated almost exclusively, if not exclusively, by the phrenic nerve ; a nerve which, having the office of supplying the most important respiratory muscle, derives its filaments from a number of sources. It arises from the third and fourth cervical nerves, receiving a branch from the fifth and sometimes from the sixth. It passes through the chest, penetrates the diaphragm, and is distributed to its under surface. . . . Its galvanisation produces convulsive contractions of the diaphragm [if so electricity applied to voluntary muscles should produce a like abnormal action], and its section paralyses the muscle almost completely. It was noticed by Lower that after section of both phrenic nerves the movements of the abdomen were reversed, and it (the abdomen) became retracted in inspiration." A similar reverse movement of the abdomen occurs in very deep inspiration.

The nerves of the lungs are supplied chiefly by the pneumogastrics, which have their origin, pneumogastric ganglion, or nucleus in the medulla oblongata of the brain. The integrity of the medulla is essential to life. If

[1] "A Text-book of Human Physiology," by Austin Flint, Jr., M.D. London, 1876, p. 125.
[2] "A Text-book of Physiology," by M. Foster, M.A., M.D., LL.D., F.R.S. London, 1891, pp. 1462, 1463, and 1464.

it be broken up and its ganglion destroyed, respiration, according to Dalton,[1] "ceases instantaneously and the circulation also soon comes to an end. Removal of the medulla oblongata produces therefore, as its immediate and direct result, a stoppage of respiration; and death takes place principally as a consequence of this fact."

From what has been stated above it would appear that the motor nerves and the muscles of the chest can act in two directions.

The following is the account given by Dalton of the connection existing between the nerves and muscles of respiration: "The movements of respiration which follow each other with incessant regularity through the whole period of life are not voluntary movements. . . . They continue uninterruptedly through the deepest slumber, and even in a condition of insensibility from accident or disease. These movements are [said to be] the result of a reflex action taking place through the medulla oblongata. The impression which gives rise to them [is said to] originate principally in the lungs, from the accumulation of carbonic acid in the pulmonary vessels and air cells, is transmitted by the pneumogastric nerves to the medulla, and is thence reflected along the motor nerves to the respiratory muscles. These muscles are then called into action, producing an expansion of the chest. The impression so conveyed to the medulla is usually unperceived by the consciousness. It is generally converted into a motor impulse without attracting our attention or giving rise to any conscious sensation. . . . During ordinary respiration each inspiratory movement is excited by the partial vitiation of the air contained in the lungs. As soon as a new supply has been inhaled the impulse to respire is satisfied, the muscles relax, and the chest collapses. In a few seconds the previous condition recurs and the same movements are repeated, producing in this way a regular alternation of inspirations and expirations.

"Since the movements of respiration are performed partly by the diaphragm and partly by the intercostal muscles, they will be differently modified by injuries to the nervous system, according to the spots at which the injury is inflicted. If the spinal cord, for example, be divided or compressed in the lower part of the neck, all the intercostal muscles will be necessarily paralysed, and respiration will then be performed entirely by the diaphragm. The chest in these cases remaining motionless, and the abdomen alone rising and falling with the movements of the diaphragm, such respiration is called 'abdominal' or 'diaphragmatic' respiration. . . . If the phrenic nerve, on the other hand, be divided, the diaphragm will be paralysed, and respiration will then be performed altogether by the rising and falling of the ribs. It is then called 'thoracic' or 'costal' respiration. If the injury inflicted upon the spinal cord be above the origin of the second and third cervical nerves, both the phrenic and intercostal nerves are at once paralysed, and death necessarily takes place from suffocation. . . . Finally, if the medulla itself be broken up so as to destroy the nervous centre in which the above reflex action takes place, both the power and the desire to breathe are at once taken away. No attempt is made at inspiration; there is no struggle and no appearance of suffering. The animal dies simply by a want of aëration of the blood, which leads in a few moments to an arrest of the circulation."

THE NERVOUS SYSTEM AS BEARING ON SENSATION, VOLITION, MUSCULAR, AND OTHER ACTION

The parts composing the several orders of plants and the lower orders of animals are as a rule very simple. They, moreover, greatly resemble each other, and are capable of independent action. A nervous system is consequently not required.

It is different with the higher animals. Here the organism consists of variously constituted parts; each part discharging a dissimilar function. In order that these parts may act in concert and consentaneously, a connecting medium becomes indispensable. This connecting medium is the nervous system. The nerves connect the various organs of the body with each other much in the same way that telegraphic wires connect different townships.

Their function is to transmit sensations from without and motor impulses from within—to co-ordinate muscular and other movements.

The nervous system increases in complexity as the animal becomes more and more differentiated.

No part of the animal economy is of greater importance, and, in some senses, less known than the nervous system. Its beginnings in the lowest animals and its powers and possibilities in the highest are virtually a *terra incognita*. It is still an open question as to whether there is not a diffuse nervous system in plants, and whether thought is not the direct product of the brain substance. The extreme sensitiveness and the distinctly co-ordinated movements of the hairs of the insectivorous plants, such as *Drosera rotundifolia*, when seizing their prey, unmistakably point to some such arrangement. The comparatively large amount of water in the nervous system and in the brain (its

[1] "A Treatise on Human Physiology," by John C. Dalton, M.D., pp. 453, 454, and 455.

highest manifestation) is significant in this connection. The brain in young animals is semi-fluid in consistence, and even in adult man contains something like 90 per cent. of water. If, however, the brain of man, the most highly elaborated and the strongest of all known brains, is 90 parts water, the existence of a still more fluid and diffuse nervous system in the lowest animals and in plants becomes not only possible but probable. There is certainly much in the movements of sensitive plants and in the lowest animals to justify such an inference. Indeed everything points to the belief that a diffuse, nearly fluid nervous system exists wherever plants and the lowest animals display definitely co-ordinated movements, that is, movements to given ends.

The discovery by Mr. Darwin of extremely delicate tenacious transparent threads in protoplasm may possibly be regarded as revealing lines of communication nervous in their nature and origin.

The nervous system in its beginning and in young animals contains next to no solid matter, and is difficult to demonstrate even with the aid of the microscope.

The nervous system only acquires consistency and becomes tangible in animals composed of several parts which move in specific directions and perform different functions. Moreover, a specially constructed brain with highly developed sense organs, and its complement of sensory and motor nerves stretching over long distances, only appears where there is a great amount of differentiation, and where the various parts of the animal are removed from each other by considerable spaces or intervals. So long as an animal consists of homogeneous parts all in contact with each other, as in the amœba, a diffuse nearly fluid nervous system would amply suffice. It would enable it to feel and move in all its parts and particles, and this the amœba actually does. Fluids spread through the amœba in all directions: there is a diffuse circulation in the absence of blood-vessels and a heart. There is no reason why there should not be a diffuse nervous system in the absence of tangible nerves. The amœba, generally regarded as structureless, is endowed with extraordinary powers. It can move every part of its body in any direction it pleases, it can select its food, and convert any part of its body into a temporary stomach: it can grow and reproduce itself and perform all the fundamental functions of life. While we should be slow to deny a possible diffuse nervous system to plants and the lowest animals, neither should we attach too much importance to the presence of a nervous system in the highest animals, where it is customary to refer the inception, initiation, and execution of every function to nerve energy, thus depriving the structures which form compound animals of powers which in many cases certainly inhere in the structures themselves. This remark applies to muscular and other movements, to the secretory and excretory processes, &c.

While uttering a word of caution as to the possible range of the nervous system, I am far from ignoring its supreme importance in the higher animals. In fact it bulks so largely in animal mechanism and movement that I feel called upon to discuss it anatomically and physiologically at very considerable length.

The function of the nervous system is primarily sensitive and secondarily motor. Feeling, however, does not necessarily imply or involve motion. The nervous system for the most part controls and regulates movements rather than causes them. It is only where highly developed brains are present that the nervous system discharges its highest functions and takes the initiative in originating movements; the movements in this case being, as a rule, voluntary in character. The points here referred to will become more apparent in discussing the development and powers of the nervous system and the nature of rhythmic and other movements.

The first trace of a nervous system is found in the medusa or jelly-fish. In this comparatively simple organism, largely composed of a jelly-looking substance varying in consistence, the nervous system is very rudimentary. It consists of delicate, transparent nerve plexuses covering large areas, of nerve cells and nerve ganglia with nerve fibres proceeding to and from them, and occasionally of nerve trunks. There is no appearance of a brain. The nervous system is in a great measure diffuse, that is, not concentrated or localised. It regulates the movements of the medusa less in detail than in the aggregate.

In the echinoderms, the five-rayed star-fish, for example (see Plate cxxxi., Fig. 2, A, p. 749), the nervous system appears in an exceedingly simple form. This quaint creature consists of a central mass from which diverge five symmetrical rays or limbs. The central mass contains the mouth and stomach; the limbs, ramifications of the stomach, glands, and muscles. The whole animal is enveloped in a *sensitive* integument.

The nervous system, with which we have more especially to do, consists of five ganglia; one of which is situated at the root of each limb. These ganglia are connected by nerve commissures to form a nervous ring which invests the mouth. The ganglia also give off two sets of branches, a sensory and motor set to each limb.

If a foreign body be made to impinge against the integument of one of the limbs, the impression is conveyed by the sensory nerves of the integument to the ganglion at the root of the limb touched. The grey matter of the ganglion converts the impact into a motor impulse which is sent out by the motor nerves to the muscles of the limb concerned. A contraction or movement of the limb ensues.

In the star-fish, constituted as explained, an impact on the external skin of any one of the limbs may result

in the movement of that limb alone, or it may result in a movement of two, three, four, or even the whole five limbs. It is a matter of intensity. If the impact be feeble, one limb only is affected; if more violent, two or more limbs. When two or more limbs are affected, the sensation is transmitted from the ganglion of the limb touched to the neighbouring ganglia by the nerve commissures: the ganglia so affected producing movements of the limbs at the roots of which they are situated. The star-fish is in a position to receive sensory impressions from without, and discharge motor impulses from within. It is provided with a nervous apparatus which enables it to perceive things outside of itself, and to move voluntarily either to seize food or escape from danger. The star-fish is not an automaton, and its movements are not reflex in the ordinary sense. It knows what it is doing, and its movements are purposive. They are not simply the result of irritation and external stimulation, as is usually believed. The star-fish can move one or more of its rays or limbs at discretion. Its nervous system, like its body, is symmetrical.

In the mollusca or soft-bodied animals the nervous system is more complicated and less symmetrical than in the echinoderms. This arises from the higher degree of differentiation attained, and the asymmetrical arrangement of the parts.

If we take the Aplysia as an example of a mollusc (see Plate cxxxi., Fig. 2, B, p. 749), we find that it is provided with a mouth, an œsophagus, a triple stomach, and a bulky liver placed to one side of the body, the gills occupying the opposite side. The whole is covered by a muscular mantle or tunic, which expands on the ventral surface into a tolerably well-developed foot or organ of locomotion.

The nervous system is non-symmetrical like the body. Thus it consists, 1st, of a small ganglion situated anteriorly, which sends filaments to the œsophagus (œsophageal or digestive ganglion); 2nd, of a larger ganglion situated posteriorly, which sends filaments to the organs of special sense (cephalic or cerebral ganglion)—this is the seat of volition and general sensation for the entire body; 3rd, a pair of ganglia which send filaments to the muscular mantle and foot (the pedal or locomotory ganglia); and 4th, a ganglion situated in the posterior part of the body which sends filaments to the branchiæ or gills (the branchial or respiratory ganglion).

In the aplysia the several ganglia are connected by nerve commissures, so that the nervous system, which extends to all parts of the body, has the whole body under command. An impact can be transmitted inwards through the sensory nerves to one or more of the ganglia, and the animal made aware of the presence of a foreign body. Conversely, a volition can be transmitted outwards through the motor nerves to the muscles, and cause movement of any part of the body.

In the articulate animals, of which the centipede may be taken as an example (see Plate cxxxi., Fig. 3, A, p. 749), the nervous system is symmetrical from the fact that the body is composed of a number of rings or segments articulated together. The segments are twenty-two in number, each segment being provided with a pair of legs, and containing a portion of the glandular, respiratory, digestive, and generative apparatus. The segments (the cephalic and caudal ones excepted) greatly resemble each other, and are mere repetitions. The cephalic segment is large, and provided with a mouth, eyes, antennæ, and jaws. The caudal segment is small, and contains the anus, &c. A symmetrical body implies a symmetrical nervous system.

The nervous system of the centipede consists of "a linear series of nearly equal and similar ganglia arranged in pairs, situated upon the median line, along the ventral surface of the alimentary canal. Each pair of ganglia is connected with the integument and muscles of its own articulation by sensitive and motor filaments, and with those which precede and follow by a double cord of longitudinal commissural fibres." [1]

The cephalic ganglia, as was to be expected, are larger than any of the others, and send filaments to the antennæ and organs of special sense. They constitute the brain of the centipede.

In the centipede the nervous system is so arranged that a volition put forth by the brain or anterior pair of ganglia can, by means of the motor nerves, cause any part of the body to move. In like manner an impact made upon the integument of any segment and transmitted by the sensory nerves to the brain is duly interpreted. The brain, by means of the motor nerves, can cause a movement in the limbs of the segment touched, or in any two or more of the segments.

In certain of the articulata, as the insects, the ganglia run more together, and are larger than in the centipede. In insects the ganglia are grouped in three principal masses, namely, the cephalic, the thoracic, and the abdominal. The cephalic is especially large, insects being remarkable for their intelligence. The thoracic is also large, this regulating the movements of the legs and wings. The abdominal presides over the digestive system. The nervous system is developed *pari passu* with the body as a whole.

In the vertebrata, under which are included fishes, reptiles, birds, quadrupeds, and man, the external parts of the body, limbs, and organs of special sense are symmetrical, as in the articulata: the internal organs of the

[1] Dalton, op. cit., p. 387.

body, especially those concerned in digestion and secretion, being unsymmetrical as in the mollusca. Here we have a cropping up and blending of two distinct types of animals. The nervous system of the vertebrata partakes of the symmetry and asymmetry of the several parts of the body to which it is distributed. Thus, that part of it which presides over the locomotory, respiratory, sensitive and intellectual functions is symmetrical, and resembles what we find in the articulata. "It is composed of two equal and symmetrical halves running along the median line of the body, the different parts of which are connected by transverse and longitudinal commissures (see Plate cxxxii., Figs. 1 and 2, p. 751).

"It occupies the cavities of the cranium and spinal canal, and sends out and receives nerves through openings in the bony walls of these cavities." It is known as the "cerebro-spinal system."

The remaining part presides over the functions of vegetative life, and is symmetrical in the neck and thorax, but unsymmetrical in the abdomen, where it is most fully developed. Its ganglia are situated on either side of the spinal column in front, in the visceral cavities of the body, and are connected, as in the other parts, by transverse and longitudinal commissures. It is known as the "ganglionic or great sympathetic system."

Considerable difference of opinion exists as to the exact nature of the so-called sympathetic and cerebro-spinal nerves. There are two leading views :[1] "According to the one, which is of old date, but which has lately been revived and ably advocated by Valentin, the sympathetic nerve is a mere dependency, offset, or embranchment of the cerebro-spinal system of nerves, containing no fibres but such as centre in the brain and cord, although it is held that these fibres are modified in their motor and sensory properties in passing through the ganglia on their way to and from the viscera and involuntary organs. According to the other, the sympathetic nerve, commonly so called, not only contains fibres derived from the brain and cord, but also proper or intrinsic fibres which take their rise in the ganglia ; and in its communications with the spinal and cranial nerves, not only receives from these nerves cerebro-spinal fibres, but imparts to them a share of its own proper ganglionic fibres, to be incorporated in their branches and distributed peripherally with them. Therefore, according to this latter view, the sympathetic nerve, though not a mere offset of the cerebro-spinal nerves, yet, receiving as it does a share of their fibres, is not wholly independent, and for a like reason the cerebro-spinal nerves (as commonly understood) cannot be considered as constituted independently of the sympathetic ; in short both the cerebro-spinal and sympathetic are mixed nerves ; that is, the branches of either system consist of two sets of fibres of different and independent origin, one connected naturally with the brain and cord, the other with the ganglia."

The vertebrata as a rule are much superior to the other classes of animals both as regards intelligence, activity, and the complicated character of their movements. Their vegetative functions, however, are but imperfectly developed. As a consequence, the cerebro-spinal system of nerves greatly preponderates over the sympathetic system. The amount of nervous matter contained in the cerebro-spinal system of even the lowest vertebrate animal exceeds by comparison that contained in the sympathetic, and the amount increases relatively as the animal becomes more and more differentiated, especially as regards intellect, sensation, and power of motion.

The spinal cord is deserving of very special consideration from the fact that it is the parent of the brain ; the brain being in reality an expansion and elaboration of the constituents of the cord, as the skull is an expansion and elaboration of the vertebræ forming the vertebral column (*vide* Plate cxxxii., Figs. 1 and 2, p. 751). The spinal cord has a common structure in the different classes of vertebrate animals.

It is composed of white and grey matter, and consists of a cylindrical cord which is attached to the brain at one extremity and extends throughout the entire spinal canal. It is a symmetrical structure, and is divided into equal parts by two fissures known as the anterior and posterior median fissures. The anterior fissure penetrates about a fourth of the cord and the posterior fissure about two-fourths ; the remaining fourth, which is composed partly of grey matter and partly of white, serves to connect the two halves of the cord together. This is known as the commissure of the cord. The anterior and posterior fissures and commissures are seen to advantage when the cord is cut across. On section the cord is observed to consist of white and grey matter, the former being disposed in six longitudinal columns and including or enveloping the latter, which appears as two crescentic columns united towards the middle. The longitudinal white columns of the cord are separated from each other by the anterior and posterior fissures, the two crescentic columns of grey matter, and the anterior and posterior roots of the spinal nerves.

The six longitudinal white columns are composed of white nerve fibres, and are known as the two anterior, the two lateral, and the two posterior columns. The nerve fibres run for the most part in a longitudinal direction, and serve to connect the various parts of the cord with each other, and the cord itself with the ganglia of the brain.

[1] Quain's "Elements of Anatomy," 7th edition. London, 1867, p. clix.

The two crescentic columns of grey matter united in the middle are to be regarded as one great compound ganglion. The white and grey columns extend throughout the entire length of the cord.

The free margins of the two crescentic columns of grey matter are designated anterior and posterior horns, from their looking respectively forwards and backwards. The band which connects the grey columns together is known as *the grey commissure;* that in front of it, which connects the anterior white columns together, as *the white commissure.*

So far the cord is quite symmetrical. It is also symmetrical as to the nerves which it gives off and receives. I say gives off and receives, because, as will be shown presently, the motor impulses travel from within outwards, the sensory impulses, on the contrary, travelling from without inwards. An examination of the cord shows that a set of nerves issues at regular intervals from either anterior white column at points corresponding to the anterior cornu of the grey columns; similar nerves joining either posterior white column at points corresponding to the posterior cornu of the grey columns.

The anterior nerves are known as the anterior roots of the spinal nerves; the posterior ones as the posterior roots. The anterior and posterior roots unite outside the spinal canal to form the spinal nerves. The anterior nerves are known as the motor or *efferent* nerves; the posterior nerves, each of which is supplied with a ganglion of grey matter at its root, as the sensory or *afferent* nerves. The spinal nerves, from the fact that they contain both motor and sensory nerves, are known as *mixed* nerves.

The sensory nerves are distributed to the integument or skin; the motor ones to the muscles. The sensory and motor nerves of the spinal column supply something like nine-tenths of the skin and muscles of the whole body, namely, those of the neck, trunk, and extremities.

The spinal nerves are given off from the spinal cord at regular intervals and in symmetrical pairs; one pair to each successive portion or segment of the body. The sensory and motor filaments are distributed, for the most part, to the skin and muscles of corresponding regions. We have here a repetition of the arrangement met with in the articulata. In the serpent, where the several divisions of the body are repetitions of each other, the spinal cord and spinal nerves are of the same size throughout. It is otherwise with those vertebrate animals furnished with four extremities, such as four legs, two legs and two wings, or two legs and two arms. In these cases the cord and spinal nerves are increased in volume in two places, namely, where the superior and inferior extremities are given off. In man the cervical nerves which go to the arms, and the sacral nerves which go to the legs, are larger than the dorsal and lumbar nerves. These nerves form the brachial and sacral plexuses respectively. There is also a cervical and lumbar expansion of the cord itself. Increase of structure begets increase of function.

The sensory nerves, as stated, are distributed to the skin, and transmit impressions or impulses from the skin to the spinal column, or to the brain. These impressions are called sensations. If they reach the brain and are recognised by it, they are termed perceptions. Perceptions imply consciousness.

The motor nerves are distributed to the muscles, and transmit impressions or impulses either from the skin (through ganglia and sensory nerves) by so-called reflex acts, or from the brain by direct acts, namely, volitions.

The sensory nerves simply transmit impulses from without; the motor nerves from within. The sensory nerves do not originate sensations, neither do the motor nerves originate movements.

Certain regions of the body are more sentient than others; the most sentient portions, as a rule, give the greatest amount of knowledge of external objects. The organs of sense afford the necessary illustration. The extremities of the fingers are more sensitive than the backs of the hands; the point of the tongue, the lips, and the orifices of most of the mucous passages being more sensitive than the trunk and the limbs. The degree of sensitiveness is ascertained with considerable accuracy by employing a pair of compasses with two sharp points; the more sensitive parts recognise the two points as distinct bodies when nearly in contact, the less sensitive parts fail to recognise the points as two bodies unless widely separated.

The degree of feeling in the higher animals depends on the ultimate ramifications of the sensory nerves and the tactile and other corpuscles in connection therewith found in the skin. If the sensory nerve to a part be divided, sensation is at once destroyed in the part. When a foreign body impinges against the skin or mucous membranes the sensation is instinctively analysed. The body touched is said to be hard, soft, rough, smooth, warm, cold, &c.

If the impact so produced be gentle, a sensation of pleasure is experienced; if violent, the sensation is one of pain. Tickling, for example, may be either pleasant or painful. In like manner the flat surface of a knife or the flat surface of a pin will produce no uneasiness; the sharp edge and point causing pain. Extreme heat and extreme cold cannot be distinguished from each other. Frozen carbonic acid and hot metal blister and destroy the skin, and as far as mere feeling is concerned resemble each other.

Ordinary sensation and pain are in some senses distinct, but they differ less in kind than in degree. Thus sensibility to pain may be diminished or suspended, while ordinary sensation remains.

This happens when chloroform or ether is administered but not carried too far. The patient is aware of the different stages of an operation and experiences no pain. If the anæsthesia be pushed beyond a certain point consciousness also disappears.

The motor nerves are distinct from the sensory ones. They transmit impulses which result in motion, muscular or otherwise. That the power of transmitting such impulses resides in the motor nerves is proved by this. If the motor nerves distributed to certain muscles be divided, the muscles cannot be moved either by an effort of will or by supposed reflex acts. The parts which suffer from division of the sensory and motor nerves are those portions of skin and those muscles to which the sensory and motor nerves are naturally distributed.

The nerves transmit influences to other structures than the skin and muscles; thus they regulate the blood supply and the degree of turgescence in a part; they also determine, within limits, the rate of the pulse, regulate the quantity of the secretion produced, &c.

Sensation and motion are usually impaired in an equal degree by shock or injury to the nervous system. In concussion or compression of the brain, for example, insensibility and loss of motion usually appear at the same instant. Sensation, however, may be impaired without loss of motion, and the converse. In tic-douloureux the sensitive parts of the face experience an agony of pain, the power of motion being in no way impaired. In facial paralysis, on the other hand, the power of motion is lost, the sensibility of the part remaining.

The fact that the sensation of a part may be impaired or destroyed, while its power of motion remains intact, and *vice versá*, originated the belief that there were two kinds of nerves distributed to different parts of the body, and such is really the case.

If the anterior root of a spinal nerve be divided in the living animal in such a manner as not to injure the posterior root, the power of voluntary motion is destroyed in the muscles to which the nerve is distributed, the skin of a corresponding region remaining sensitive.

If, on the contrary, the posterior root of a spinal nerve be divided in the living animal in such a manner as not to injure the anterior root, that part of the skin to which the nerve is distributed ceases to be sensitive, the power of voluntary motion in the muscles of a corresponding region being in no way impaired.

From this it follows that sensations travel through the posterior roots in a direction from *without inwards;* motor impulses travelling through the anterior roots in a direction from *within outwards*.

Two sets of nerves discharging dissimilar functions are also found in the spinal cord. The anterior columns of the spinal cord are *motor* in their nature; the posterior columns of the spinal cord, on the contrary, are *sensory*.

"The anterior and posterior columns of the cord are accordingly so far analogous in their properties to the anterior and posterior roots of the spinal nerves."

The routes pursued by the motor and sensory impulses in the spinal cord have been ascertained with a considerable degree of certainty by Majendie, Longet, Brown-Séquard, and Vulpian.

The motor impulse which produces voluntary motion travels along the white substance of the anterior and lateral columns of the spinal column in a direction from above downwards, whereas the sensory impulse travels along the deeper portion of the cord by filaments which pass through the grey matter in a direction from below upwards.

These points are proved as under. If the antero-lateral columns be cut across in the living animal, all power of voluntary motion in the parts below is lost. If, on the other hand, the grey substance and anterior portions of the cord be cut across (the posterior columns being left intact), the power of sensation is destroyed.

It follows from this "that while the posterior columns are sensitive to artificial stimuli they are not the portions through which the sensitive impressions are directly conveyed from the posterior roots of the nerves." Vulpian is of opinion that possibly the posterior columns act as longitudinal commissures, and connect different portions of the length of the cord with each other.

The function performed by the spinal cord so far as explained is that of transmission. An impact is made on the peripheral portions of the sensory nerves known as a sensation. It travels from without inwards through the posterior roots of the spinal nerves, and passes upwards along the communicating fibres of the cord to the brain, where it is converted into a perception.

Conversely, an effort of will or a volition is made by the brain. It travels from above downwards by the longitudinal fibres of the antero-lateral column, and from within outwards by the anterior roots of the spinal nerves to produce muscular motions.

The spinal cord is provided with oblique and transverse fibres. It is also characterised by a crossed action. If we trace the anterior columns in a direction from below upwards we shall find that their fibres cross or decussate a little below the point where the cord expands to form the medulla oblongata.

The fibres of the right anterior column pass over to the left side of the medulla oblongata, and so reach the

left side of the brain. The fibres of the left anterior column in like manner pass over to the right side of the medulla oblongata and thence to the right side of the brain.

The decussation of the fibres of the anterior columns in the vicinity of the medulla oblongata is all important, as it enables us to explain how lesions of the right side of the brain affect the left side of the body and *vice versâ*.

The decussation can be readily seen by gently separating the anterior pyramids; the fibres crossing obliquely at the root of the anterior fissure. There are grounds for believing that the fibres of the anterior columns also cross in the anterior commissure throughout the cervical portion of the spinal cord.

The crossed action of the motor filaments constituting the anterior columns is proved in the living subject by various brain lesions, such as softening and apoplexy: also by mechanical pressure due to depression of the skull, the presence of tumours, abscesses, &c.

Thus if there be softening, clot, or pressure on the right side of the brain, there is, as a rule, more or less complete paralysis of the left side of the body. If, on the other hand, the seat of the injury is the left side of the brain, it is the right side of the body which is paralysed.

If the lesion occurs where the fibres of the anterior columns decussate, the paralysis affects both sides of the body; and if it be below the decussation and confined to one column, that side of the body corresponding to the column only is affected. This happens when either of the anterior columns is injured in the dorsal or lumbar regions. In such cases paralysis of voluntary motion occurs in the muscles of the injured side below the seat of injury. Thus injury to the dorsal or lumbar portion of the right anterior column is followed by partial or complete paralysis of the right side of the body below the injured point; injury to the left anterior column being accompanied by paralysis of the left side of the body.

It is otherwise with the right and left sides of the brain. Here, because of the decussation of the anterior columns, as explained, the action is invariably crossed; injury to the right side of the encephalon resulting in paralysis, total or partial, of the left side of the body and *vice versâ*.

While there is a crossed action of the *motor filaments* of the cord, there is also a similar crossed action of the *sensory filaments*. This fact was first fully established by Dr. Brown-Séquard (1853). He showed that the sensory fibres, unlike the motor ones, cross throughout the entire extent of the cord; the crossing of the motor filaments, as explained, being confined to the upper portion of the cord. As soon as the sensory fibres of the right spinal nerves enter the cord they pass over to the left side; the sensory fibres of the left spinal nerves passing over to the right side.

Dr. Brown-Séquard also succeeded in demonstrating that the sensory filaments of the spinal nerves on first entering the cord join the posterior columns, which are exceedingly sensitive, and immediately after pass through the central parts of the grey matter, and so reach the opposite side of the cord. From this it follows that the posterior columns consist of different nervous filaments, which are being constantly added to them on one side from below, and which as constantly leave them on the other to pass upwards to the brain. Division, therefore, of the posterior columns does not destroy sensibility in all the nerves behind the seat of injury, but only in those which enter the cord at the point of section.

The filaments of the motor and sensory nerves are distinct and independent throughout their entire courses—that is, each nerve fibre discharges a function peculiar to itself, irrespective of all the others. If this were not the case, confusion would constantly arise, not only in the execution of muscular movements, but also in the perception of sensations.

That the filaments of the motor nerves act independently admits of easy proof. If the sciatic nerve of a frog be divided, and some of the filaments separated from the trunk of the nerve and stimulated, movement occurs only in such muscles as are supplied by the filaments. Other proofs may be adduced: certain muscles—for example, the extensors and flexors of the fingers—are supplied by the same nerve. If the filaments constituting the nerve did not act independently they could not cause the extensors to shorten when the flexors elongated, and *vice versâ*. The fact that the filaments of the same nerve can produce this double result shows, I think, very plainly, that the peculiarity of muscular movements is to be attributed to a double and opposite power of motion inhering in the sarcous elements of the muscle, and not to any peculiarity in the nerves.

As previously stated, the sarcous elements of an extensor and flexor muscle are always arranged at right angles to each other. A common impulse, therefore, transmitted through the filaments of a motor nerve causes the extensor to shorten when the flexor lengthens, and the converse. A still better example is to be found in the muscular movements of the eyeballs. Here the internal rectus muscle of the right eye shortens while the external one lengthens; the internal rectus muscle of the right eye shortening at the same time that the external rectus muscle of the left eye is shortening. Here is a double crossed action which cannot be explained by any peculiarity of the nervous supply.

The movements of the eyeballs are known as associated movements. They are correlated, and so resemble the movements of the flexor and extensor muscles.

That the filaments of the sensory nerves also act independently of each other is proved by a very simple experiment. If the skin be pricked with a pin, pain is experienced only at the seat of injury. In other words the pain is not diffused. Certain sensations and movements are produced simultaneously, and are known as *associated* sensations and movements.

Tickling of the soles of the feet produces a peculiar feeling at the epigastrium. The muscles of the eyeball all work together, although apparently playing at cross purposes.

The spinal cord in one sense may be regarded as simply a great nerve consisting of motor and sensory filaments which connect the muscles and integument with the brain, and assist in producing voluntary motions and conscious impressions. The spinal cord, however, is more; it is a great ganglionic centre, capable of independent action. It can receive sensory impulses and convert them into motor ones irrespective of the brain proper. This function of the spinal cord is generally known, and designated as its reflex function.

If a frog be decapitated, it is found that, though consciousness and sensation in the ordinary sense are destroyed, the power of motion remains. This is proved by stimulating the integument, say, of one of the extremities.

If the stimulus be weak, the muscles of that extremity only move; if powerful, two or even all the muscles of the extremities are brought into action. These movements are occasioned by the sensory nerve distributed to the integument carrying impulses to the ganglia of the spinal cord, the ganglia sending out impulses by the motor nerves to the muscles, and causing them to move. The brain takes no part in these movements, as it is removed when the frog is decapitated.

So-called reflex movements can only take place when the skin and muscles are connected with the spinal cord by nerve filaments, and when the spinal cord itself is structurally perfect.

If either the anterior or posterior roots of the spinal nerves be divided, no supposed reflex action can take place—the machinery by which it is believed to be produced being destroyed.

In the so-called reflex movements the sensory impulse passes upwards along the sensory nerves to the posterior roots of the spinal nerves—thence to the grey matter of the cord; it is then reflected downwards and backwards along the motor filaments of the anterior roots of the spinal nerves to the muscles, muscular movements being thus engendered. Reflex movements when they occur, it will be seen, are indirectly produced.

Reflex action is chiefly confined to the spinal cord. It can be produced perfectly when the brain and sympathetic system of nerves are removed. It therefore requires no exercise of will, consciousness, or judgment. Even ordinary sensation is not necessary.

Reflex movements are constantly occurring, although not usually noticed, as in sudden withdrawal of the hand from the fire, regaining of one's balance, &c. In such cases the brain has not sufficient time to act.

The spinal cord regulates the movements of the sphincters of the bowel and bladder. If it be injured in its upper or middle portion, sensibility and voluntary action of the sphincters are lost; therefore the discharges are involuntary and unconscious.

Injury of the spinal cord produces paralysis of the bladder. The urine collects until the bladder is full, and then it overflows and dribbles away in a more or less constant stream.

Injury of the spinal cord exercises an effect upon nutrition, secretion, animal heat, &c., in the paralysed parts.

The spinal cord, regarded as a nerve centre, exerts a general protective action over the whole body. It presides over the voluntary movements of the limbs and trunk; it regulates the action of the sphincter of the bladder and that of the rectum. It also exerts an indirect influence on the nutrition of those parts which it supplies with nerves.

The foregoing description of the anatomy and physiology of the spinal cord will, it is hoped, considerably simplify the description of the anatomy and physiology of the brain. The anatomy and physiology of the brain are admittedly very difficult. They are best approached from the comparative anatomy side. Taking the spinal column as the parent and precursor of the brain, it is comparatively easy to trace its development.

§ 219. The Brain.

At the outset it may be well to explain that the encephalon includes the whole of that portion of the cerebro-spinal system contained within the cranial cavity.

It consists of three principal parts, namely, the cerebrum, the cerebellum, and the medulla oblongata. The

cerebrum, cerebellum, and medulla oblongata are composed of a double series of nervous ganglia connected with each other and with the spinal cord by transverse and longitudinal commissures. The number and size of the ganglia vary in different animals according to the degree of intelligence and special endowment.

Thus in the fish—the cod, for example—the brain is composed of five pairs of ganglia or nerve centres arranged the one behind the other in linear series and on the same plane (see Plate cxxxi., Fig. 4, A, p. 749). The fish feels, sees, tastes, smells, and hears after a fashion. It is capable of all kinds of voluntary movements, and displays a low form of intelligence. Trout frequently fished and pricked by the hook become very wary; gold-fish and carp can be collected for feeding purposes by the ringing of a bell; and ground fishers maintain that the odour of the bait attracts fishes and even draws them up stream.

The brain of the reptile, as witnessed in the alligator (see Plate cxxxi., Fig. 4, C, p. 749), closely resembles that of the fish, with this difference, that the cerebral lobes are more fully developed. This fact fully accounts for the superior intelligence of the reptile as compared with the fish.

The brain of the alligator consists of five pairs of ganglia, arranged the one behind the other in the following order from before backwards :—

(*a*) The olfactory ganglia.
(*b*) The cerebral ganglia or hemispheres.
(*c*) The optic ganglia.
(*d*) The cerebellum.
(*e*) The medulla oblongata.

The functions discharged by these ganglia are described further on under the human brain.

In birds the cerebral ganglia or hemispheres are larger than in the reptiles, and extend backwards so as partly to conceal the optic ganglia or tubercles. The cerebellum is likewise well developed in birds, and projects backwards so as almost completely to cover the medulla oblongata and fourth ventricle. It further presents on its surface a number of transverse foldings or convolutions. Birds, especially birds of prey, are remarkable for their activity and brain power.

In quadrupeds the cerebral ganglia or hemispheres are still more developed as compared with the rest of the brain. Two additional pairs of ganglia are likewise added, namely, the corpora striata and optic thalami. In the rabbit (see Plate cxxxi., Fig. 4, D, p. 749), proceeding from before backwards, the following ganglia are met with :—

(*a*) The olfactory ganglia.
(*b*) The cerebral ganglia or hemispheres.
(*c*) The corpora striata.
(*d*) The optic thalami.
(*e*) The corpora quadrigemina.
(*f*) The cerebellum.
(*g*) The medulla oblongata.

The cerebellum in the rabbit is greatly developed laterally, and presents an abundance of transverse convolutions. It conceals the fourth ventricle and most of the medulla oblongata.

In certain quadrupeds the cerebral ganglia or hemispheres increase to such an extent as to cover the olfactory ganglia in front and the tubercula quadrigemina and cerebellum behind. The surface of the hemispheres also becomes covered with convolutions disposed in curvilinear lines. This arrangement greatly increases the extent of grey matter in any given area of the brain; this grey matter being more especially connected with the manifestations of intelligence. That many animals reason, and reason acutely, is not now seriously denied. The convoluted arrangement attains its highest development in man, and in him also the cerebral ganglia or hemispheres attain their greatest size. In man the cerebral hemispheres, when seen from above, conceal all the other ganglia, a slight portion of the cerebellum excepted. They form in reality nine-tenths of the whole brain, a circumstance sufficient in itself to explain the extraordinary intelligence possessed by man as compared with the lower animals. The parts described in the brains of quadrupeds also exist in the human brain with certain additions. Thus, proceeding from before backwards, we find in the human brain the following :—

(*a*) The olfactory ganglia.
(*b*) The cerebral ganglia or hemispheres.
(*c*) The corpora striata.
(*d*) The optic thalami.
(*e*) The tubercula quadrigemina.
(*f*) The cerebellum.

(*g*) The ganglion of the tuber annulare.
(*h*) The ganglion of the medulla oblongata.
(See Plate cxxxii., Fig. 4, p. 751.)

As the ganglia of the human and other brains perform different functions it is necessary to say a few words regarding each. I take them in the order given above.

§ 220. Olfactory Ganglia.

These supply branches to the mucous membrane of the nose. They are the organs of smell, and are sparingly developed in man, but in some of the lower animals of keen scent attain a large size. The olfactory ganglia are connected with the base of the brain by two commissures. The ganglia and commissures are principally composed of grey matter.

§ 221. Cerebral Ganglia or Hemispheres.

These in man are enormously developed. They tower above and cover in all the other ganglia, and are to be regarded as radiating expansions and elaborations of the spinal cord. They are composed of grey and white nerve matter; their surfaces being deeply convoluted. They contain molecules, nerve cells, ganglia, neurons, conducting fibres, &c., in incredibly large numbers. Their function is unquestionably intellectual. If they are injured, or partly removed, or diseased, the intellectual faculties inevitably suffer; the impairment of brain power corresponding with the extent of the lesion, however caused. According to Ferrier the anterior portions of the cerebral hemispheres are the chief centres of voluntary motion.

§ 222. Corpora Striata.

These occur on the under surface of the brain, and occupy a somewhat anterior position. They are large, square-shaped ganglia, and are supposed to be connected in some way not understood with sensation and volition.

§ 223. Optic Thalami.

These have been misnamed. They are not the organs of vision. This was conclusively proved by Longet, who broke up the optic thalami in birds with needles without impairing either the power of sight or the sensitiveness of the pupil. He thinks they exercise a crossed action on the voluntary movements. Ferrier is of opinion that they are connected with sensation.

§ 224. Tubercula Quadrigemina.

The tubercula quadrigemina, though comparatively small, are very important ganglia. They give origin to the optic nerves, and preside over the sense of sight. They are sometimes called the "optic ganglia." They are large in fishes, reptiles, and birds where the eyes are large. They are comparatively small in quadrupeds and in man. That the tubercula quadrigemina are intimately and primarily connected with sight is proved by the fact that if they be broken up, or the nerves which proceed from them be divided, *complete blindness is at once produced.*

It is in the tubercula quadrigemina that the impression of light is perceived. Ferrier believes that the tubercles also act as centres for the extensor muscles in the head, trunk, and legs.

§ 225. Cerebellum.

The cerebellum is situated quite behind, and covers in, the fourth ventricle and the posterior surface of the medulla oblongata. It is believed to associate or co-ordinate the different voluntary movements. According to Ferrier the cerebellum is the co-ordinating centre for the muscles of the eyeball. Each separate lobule (in rabbits) is a distinct centre for special alterations of the optic axes. On the integrity of these centres depends the maintenance of the equilibrium of the body.

§ 226. Tuber Annulare.

The tuber annulare is a small but very important ganglion situated at the base of the brain. It lies in the course of the ascending fibres of the anterior and posterior columns of the cord, and occupies a central position

in the brain. It is intimately connected with the functions *of sensation and voluntary motion.* These functions, as already stated, are discharged after both the cerebrum and cerebellum are removed. According to Longet the power of sensation and voluntary movement remain after the cerebrum, cerebellum, olfactory ganglia, optic tubercles, corpora striata, and optic thalami are completely removed—when, in fact, nothing remains in the cavity of the cranium but the tuber annulare and the medulla oblongata. (This proves that sensation and voluntary motion may occur in animals with no very elaborate or exalted nervous system.) If, however, the tuber annulare be broken up *all manifestations of sensation and volition cease, and apparently consciousness also.*

The only movements which under these circumstances can be produced artificially are occasional convulsive movements due to supposed reflex action. The only other movements which take place are those of respiration and circulation, and these cease after a while.

The ganglion of the tuber annulare is to be regarded as that by which impressions conveyed inward through the nerves are first converted into conscious sensations, and in which the voluntary impulses originate, which produce muscular movements in various parts of the body.

In making this statement it is necessary to bear in mind that a simple sensation is not to be confounded with the ideas which it originates, nor an action of volition with the train of thought which leads to it.

These are mental operations which take place in the cerebrum. *Mere sensation and volition may occur independently of intellect after the cerebrum is destroyed.* "We distinguish, then, between the simple power of sensation and the power of fully appreciating a sensitive impression, and of drawing a conclusion from it. We distinguish also between the intellectual process which leads us to decide upon a voluntary movement and the act of volition itself. The former must precede, the latter must follow. The former takes place, so far as experience can show, in the cerebral hemispheres; the *latter in the ganglion of the tuber annulare.*" [1]

§ 227. Medulla Oblongata.

A very important ganglion, known as the pneumogastric ganglion or nucleus, is contained in the middle and posterior portions of the medulla. It is embedded in the substance of the restiform body, and from its intimate connection with life is occasionally designated "the vital point or knot." As has been already shown, all the other parts of the brain may be injured or destroyed without immediate destruction of life. If, however, the medulla and its ganglion be broken up or destroyed, death inevitably and speedily results from a stoppage of the respiration.

The ganglion of the medulla is said to regulate the respiratory movements by a reflex action. These movements are involuntary and rhythmic in their nature, and in this respect resemble the movements of the heart.

The medulla oblongata is important from its being the first expansion of the spinal cord—the first instalment, so to speak, of the brain, and the great respiratory centre. It consists of:—

(*a*) The anterior pyramids.
(*b*) The olivary bodies.
(*c*) The restiform bodies.

The anterior pyramids are continuations of the anterior columns of the cord. They pass upwards beneath and through the transverse fibres of the pons Varolii and then radiate to terminate in the grey matter of the cerebral lobes or brain proper. The anterior columns, as already explained, decussate below the pyramids. The optic thalami and corpora quadrigemina also decussate. The olivary bodies occupy the same position as the lateral columns of the cord. They are rounded bodies, each of which contains in its interior a thin layer of grey matter folded upon itself to form a convoluted ganglion. The ganglia of the olivary bodies are connected by longitudinal, radiating, and transverse fibres with each other, and with the other parts of the medulla above and below. The restiform bodies are continuations of the posterior columns of the cord. They diverge superiorly to form part of the walls of the fourth ventricle, and are exceedingly important from the fact that they contain in their substance a ganglion which gives origin to the pneumogastric nerve and regulates the respiratory movements. The filaments of the restiform bodies pass upwards, and are distributed partly to the grey matter of the cerebellum and partly to the grey matter of the cerebrum.

The elements forming the spinal cord can be traced into the cerebellum, or little brain, and into the cerebrum, or greater brain. The cerebellum is also an expansion of the spinal cord. Its function is largely to assimilate and co-ordinate voluntary muscular movements.[2]

[1] "A Treatise on Human Physiology," by John C. Dalton, M.D., p. 453.

[2] If a portion of the cerebellum of a pigeon be removed, the bird exhibits uncertainty in its gait and an irregular movement of the wings. If a larger part be taken away, the bird loses the power of flight and walks or stands with great difficulty. *This is not due to paralysis of the extremities but to a want of co-ordinating power.* The movements made by the legs and wings are energetic and rapid, but they are blundering and ineffectual. The bird reels and tumbles, but can neither walk nor fly.

The hemispheres of the cerebrum are united by the corpus callosum, and the two halves of the cerebellum by the pons Varolii. These form transverse commissures.

The great transverse commissure of the cerebrum consists of a layer of white substance situated at the bottom of the longitudinal fissure. It consists of white fibres which arise in the grey matter of one hemisphere, converge and then diverge, to become connected with the grey matter of the opposite hemisphere.

Similar remarks are to be made of the pons Varolii. While the most numerous and important fibres of the corpus callosum connect corresponding convolutions of the cerebral hemispheres of opposite sides, certain of the fibres decussate with the fibres of the peduncular system, passing to the same convolutions. But smaller groups of fibres also cross the mesial plane. The anterior commissure, for example, as was pointed out by Spurzheim half a century ago, passes between and connects the convolutions of the opposite temporo-spheroidal lobes, and in its course traverses the two corpora striata, which in all probability it also brings into anatomical connection with each other. The posterior commissure, again, connects the two optic thalami.

The entire brain is to be regarded as a series of ganglia connected with each other by longitudinal and transverse commissures. Precisely similar remarks are to be made of the spinal cord. The brain and spinal cord (cerebro-spinal system) cannot be severed or dissociated: they are complemental parts of each other. They consist of a series of ganglia symmetrically arranged and united by nerve fibres and commissures to form a complex whole. The ganglia of the spinal cord furnish nerves to the skin and the muscles of the neck, trunk, and extremities; the ganglia of the brain supplying corresponding parts of the head, and, in addition, the organs of special sense.

The sensory and motor nerves can be readily distinguished from each other in the different parts of the body, and in the spinal cord. These nerves can also be detected, though to a less degree, in the brain.

The sensitive and motor nerves in the brain, considering its volume, are comparatively few in number. The only parts of the brain which, according to Longet, are sensitive are situated at its base. They are the posterior surface of the medulla oblongata, the restiform bodies, the *processus e cerebello ad testes*, and the upper part of the *crura cerebri*. These, it will be remembered, are continuations of the posterior columns of the cord which are also sensitive.

The olfactory ganglia, *the corpora striata*, *the tubercula quadrigemina*, and the white and grey substance of the cerebrum and cerebellum, according to the same authority (Longet), are insensitive. The parts of the brain which contain motor fibres are, according to Longet, also situated at the base. They are the continuations of the anterior columns of the cord, and form the anterior surface of the medulla oblongata, the tuber annulare, and the lower part of the *crura cerebri*. This authority affirms that the olfactory ganglia, *the corpora striata*, *the optic thalami*, *the tubercula quadrigemina*, the white and grey substance of the cerebrum and the cerebellum, cannot produce motion.

Recent investigations and experiments show that the brain possesses a much larger number of sensitive and motor nerves than have been ascribed to it by Longet. It is, however, to be noted, as I have already explained, that the sensory nerves which are found on the surface of the brain have been in a large measure rendered functionally inactive from disuse; the bony walls of the skull preventing, in great measure, impacts from without. The motor nerves of the brain are, from a like cause, not readily acted upon by external stimuli.

The very marked development of the cerebral ganglia in man as compared with the other representatives of the vertebrate series (the monkeys included) is strikingly suggestive. Wherever there is increased development and differentiation of structure, there is increased function. The great mental grasp of man is doubtless referable to the great size of his cerebral lobes or ganglia. These lobes, also called hemispheres, are composed of white or conducting matter and grey or ganglionic matter; the latter elaborating and evolving nerve force. Both kinds of matter are very richly supplied with blood; the quantity of this precious fluid circulating within the brain being about one-fifth of the whole blood in the body. This one fact accounts for the great functional activity of the brain as a whole, and of the cerebral lobes or hemispheres in particular. The grey or ganglionic matter of the cerebral lobes envelops and includes the white matter, and the surface of the lobes is deeply and intricately convoluted. The arrangement enormously increases the area of the grey matter, which is crowded with nerve cells, ganglia, and neurons which communicate, interlace, and give off an infinite number of terminal and other nerve filaments, a large proportion of which seek the surface of the cerebral lobes. These nerve cells, ganglia, and neurons, and the molecules forming them, are connected in some mysterious way with every manifestation of nerve force, and with intellect as the highest product of nerve force. Taken together, they form a battery of nerve force the intensity of which cannot be accurately estimated in the present state of physiological science. The white matter enters each convolution, and sends strands of nerve filaments to the grey or ganglionic matter. The strands of nerve filaments are connected with the nerve cells of the grey matter of the brain, and with the other nerves of the body. In virtue of this arrangement the cerebral ganglia can receive impressions from all parts of the body, and control

its voluntary movements. The cerebral ganglia, lobes, or hemispheres are to be regarded as more strictly the organs of the mind. If they be removed or diseased the intellectual edifice totters and falls. There is loss of memory, judgment, and the power of willing. Under these circumstances the individual is in the condition of a machine working by the supposed reflex action of the remainder of the cerebro-spinal axis. The integrity of the cerebral hemispheres is necessary to the production of intelligence and will, but in what particular part of the hemispheres these powers reside is not yet determined. The cerebral hemispheres display reflex acts similar to those said to be displayed by the spinal cord. Winking at a flash of light, starting at a loud noise, or recovering one's balance, afford examples of intellectual reflex acts. When the mind is preoccupied, various mental acts are performed quite unconsciously. These acts are largely the result of habit. Education proceeds on the power which the nervous system possesses of converting what were conscious actions into more or less unconscious actions, reflex in character. A good musician after a time plays his instrument automatically. The doctrine of "Association of Ideas" largely rests upon habit and associated molecular brain movements; one mental condition calling up another automatically.

The analogy known to exist between the brains of animals and that of man explains why animals are intelligent and are capable of reasoning within limits. The similarity of structure in the brains of animals and man sufficiently accounts for the resemblance of function. That those parts of the brain known as the cerebral ganglia or hemispheres are the seat of intelligence is proved directly by experiment and indirectly by observation. In some of the lower animals the hemispheres may be removed without destroying either sensation or volition in the parts of the brain which remain *in situ*. This is the case in birds. The effect of the mutilation is simply to plunge the bird into a state of profound stupor. If a pigeon be employed, the bird sits motionless with closed eyes and the head sunk between the shoulders. The feathers are semi-erect, the bird appearing larger than usual. This state of immobility is not accompanied by loss of volition, voluntary motion, sight, hearing, or of ordinary sensibility.[1]

The eyes and head will follow the movements of a lighted candle. The bird starts on the report of a pistol. It also moves away if pinched or injured. It is, however, listless and incapable of forming mental associations or of perceiving a relation between external objects. The report of the pistol produces no alarm or sense of danger. The memory is altogether destroyed, and the sensation perceived the one instant is forgotten the next. The limbs and muscles are under the control of the will, but the will itself is inactive. The powers lost by the destruction of the cerebral hemispheres are of a mental or intellectual character. The bird apparently cannot compare different ideas or perceive how the one is related to the other.

If the cerebellum of a pigeon be destroyed wholly or in part, the phenomena witnessed are very different. The bird, instead of being dull and listless, is in a state of constant agitation. It is readily terrified, and makes violent and fruitless efforts to escape. Its movements are sprawling and unnatural, and are evidently not controlled by the will. It can neither stand, walk, nor fly. These experiments, particularly on the cerebrum, go to show that the brain proper is the seat of intellect, and that intellect bears a relation to the quantity of brain matter.

Similar results are observed in man, when the cerebral hemispheres are the seat of organic lesions. In impending apoplexy or softening of the brain one of the most constant symptoms is a partial or complete loss of memory. This is followed by a want of discriminating power as to what is important and unimportant in matters of daily life. Trifling events are magnified unduly, while important ones are treated lightly.

As the disease advances, the patient becomes more and more imbecile. He loses intelligence, memory, and judgment.

That the brain and the cerebral ganglia or hemispheres of the brain are directly concerned with intellect is confirmed and demonstrated by this, that the most intelligent animals have always the largest brains. This holds true of the whole animal kingdom, lower animals, and also of man.

The cerebral ganglia are more fully developed in man as compared with the other parts of the brain than in any other animal. These in reality constitute nine-tenths of the whole brain. Man as a consequence is endowed with the highest degree of intelligence. While man is intellectually superior to all animals, he is inferior to some of the lower animals in the acuteness of the special senses. He has not the keen scent of the dog, neither has he the far-reaching eye of the bird.

The semi-civilised nations have smaller brains than the European, the advance in the arts in Europe being due to this circumstance.

Amongst Europeans, the brain capacity varies; but *cæteris paribus* the larger brain is the more powerful.

In estimating brain power, however, quality as well as quantity is to be taken into account. There are such

[1] This fact seems to prove that we may have sensation or general sensibility and special sense organs apart from a brain proper. This state of things actually exists in the lower animal forms.

things as large soft heads and small hard ones. The Greek heads are less remarkable for their size than for their exquisite symmetry. A head to be great must be well balanced, and this is a characteristic of the typical Greek head. A lop-sided head is not great as a whole, but only in one direction.

A well-balanced, energetic head generally leads to success in life. We all start from the same platform of profound ignorance, and the rule is that great men are the product of great brains. The intelligent alone can educate themselves and take advantage of the times.

If we look at the various races of mankind we shall find that there is a gradual advance as regards the degree of development of the brain (particularly the cerebral lobes or ganglia) and the degree of intelligence displayed (*vide* Fig. 225). The low, narrow forehead of the negro, Hottentot, and analogous forms contrasts strongly with

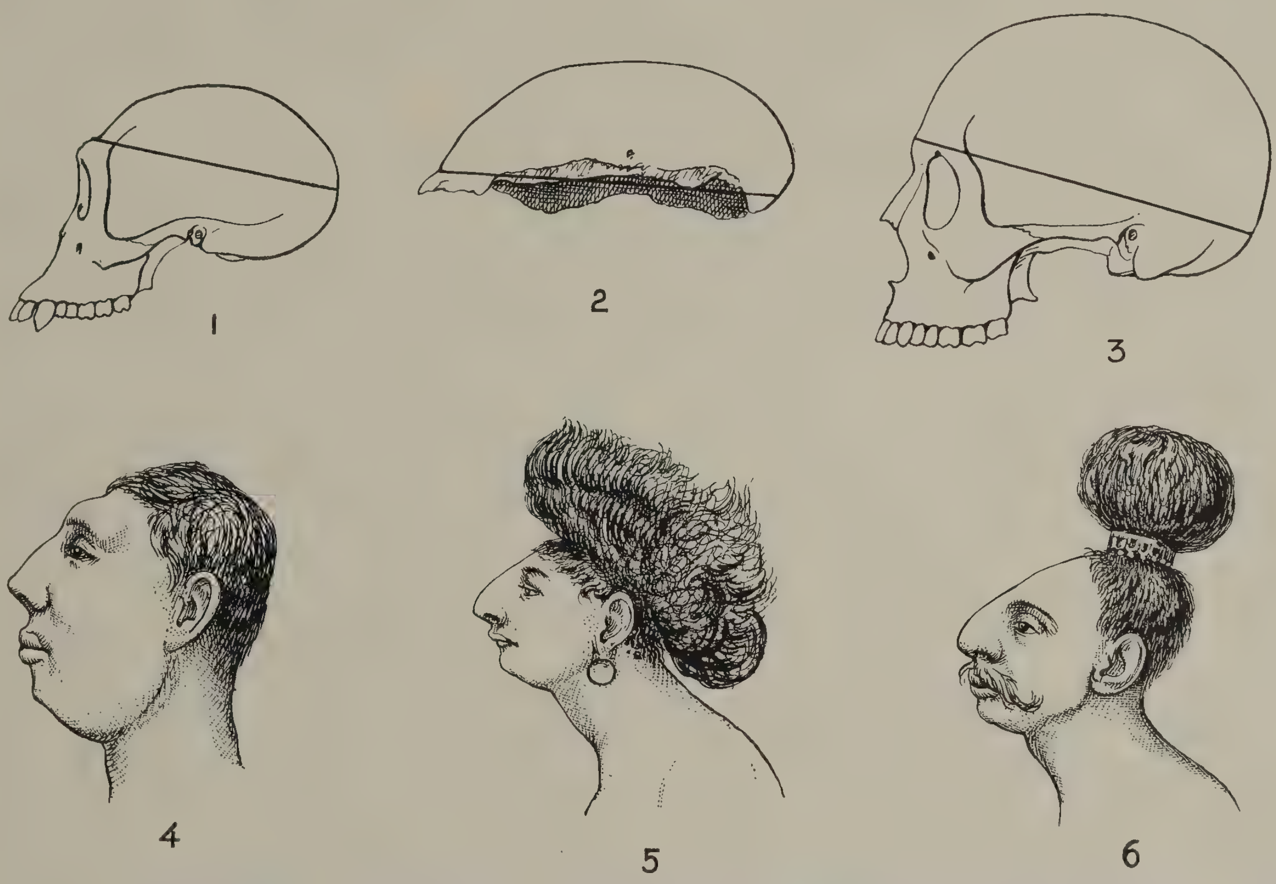

Fig. 225.—1, Skull of chimpanzee (*Troglodytes niger*); 2, "Calvaria" of so-called "monkey-man," Pithecanthropus; 3, Normal skull of modern man; 4, Head of idiot, from a cast from life by C. Polini of Manchester; 5, Head of the so-called "Last of the Aztecs," the woman Bartola; 6, Head of the so-called "Last of the Aztecs," the man Maximo. From photographs (of Aztecs) taken in 1904.

the lofty broad forehead of the European, and the mind of the former, as is well known, is rudimentary when compared with that of the latter. The forehead of the negro, Hottentot, &c., in turn contrasts strongly with that of the chimpanzee, orang-utang, and gorilla. But the intelligence of the negro, Hottentot, &c., is as much superior to that of the chimpanzee, orang, and gorilla as that of the European is superior to the intelligence of the negro, Hottentot, &c. The question of brain volume as a measure of capacity or intelligence is illustrated by a reference to the heads of idiots. These, for the most part, have low foreheads and small brains. It is also illustrated by a reference to the heads of animals. Those animals are always comparatively the most intelligent which have the largest brains in proportion to the size of their bodies. The actual amount of brain is never to be lost sight of. The elephant, with the exception of the whale, has the largest brain of any living animal. The elephant, however, is known to be one of the most sagacious of animals. Whether, therefore, we look at the volume of the brain as compared with that of the body, or the actual amount of brain substance, we are compelled to believe that in proportion to the development of the brain, so is the degree of intelligence displayed. It ought to be mentioned in this connection, that in the young of all animals the brain is comparatively largely developed, and here it is that the quality of the brain requires to be considered. The actual quantity of brain in a young animal is larger than in the adult, but the organ is in a quasi-fluid condition, and very defective as regards quality.

The mental manifestations of a child very nearly correspond with those of certain of the lower animals—the dog, for example—and children and dogs as a rule are fast friends. While the great majority of anatomists and physiologists have no difficulty in associating all manifestations of intellect with the brain and certain molecular brain changes occurring in the nerve cells, ganglia, neurons, &c., it is otherwise with those who reject matter as the substratum of intellect, who group the intellectual faculties under the abstract term "mind," and who maintain that the mind is immaterial in its nature. It is interesting to compare the views of the so-called materialists and immaterialists. Huxley says: "Protoplasm is but an aggregate of physical materials exhibiting in combination new properties . . . all vital acts whatever, *intellectual included*, are but the result of the molecular force of the protoplasm which displays it." This view is supported by many striking facts, as I have already explained. A violent blow on the head obliterates the mind for the time being. Disease and softening of the brain produce insanity or some form of imbecility. The mind expands *pari passu* with the growth of the brain in the child, it attains its highest development in mature manhood, and it loses power when the organ shrivels in old age. The mind has its first and second childhood, corresponding to the increase of brain substance in youth and decrease in senility.

My late distinguished friend, Sir William Lawrence, who was much in advance of his time when he wrote in 1822,[1] observes: "There would be little inducement to compare together the various animal structures, to follow any apparatus through the whole animal series, unless the structure were a measure and criterion of the function. . . . The same kind of facts, the same reasoning, the same sort of evidence altogether, which show digestion to be the function of the alimentary canal, motion of the muscles, and various secretions of their respective glands, prove that sensation, perception, memory, judgment, reasoning, thought—in a word, all the manifestations called mental or intellectual—are the animal functions of their appropriate organic apparatus, the central organ of the nervous system.

"No difficulty or obscurity belongs to the latter case, which does not equally affect all the former instances; no kind of evidence connects the living processes with the material instruments in the one, which does not apply just as clearly and forcibly to the other. . . . In opposition to these views it has been contended that thought is not an act of the brain but of an immaterial substance residing in or connected with it. This large and curious structure, which, in the human subject, receives one-fifth of all the blood sent out from the heart, which is so peculiarly and delicately organised, nicely enveloped in successive membranes, and securely lodged in a solid bony case, is left almost without an office, being barely allowed to be capable of sensation."

That mind is the product of an immaterial something located in the brain is mere hypothesis—a doctrine which derives no support either from observation or experiment. "If," continues Sir William, "the intellectual phenomena of man require an immaterial principle superadded to the brain, we must equally concede it to those more rational animals which exhibit manifestations differing from some of the human only in degree. If we grant it to them, we cannot refuse it to the next in order, and so on in succession, to the whole series—to the oyster, the sea-anemone, the polype, and microscopic animalcules. Is any one prepared to admit the existence of immaterial principles in all these cases? If not he must equally reject it in man. . . . Who knows the capabilities of matter so perfectly, as to be able to say it can see, hear, smell, taste and feel, but cannot possibly reflect, imagine, judge?" Some have thought that if the mind is material there can be no immortality of the soul. This, however, does not follow, as matter, like force, is indestructible. What especially distinguishes man from all other animals is his intellect. While some of the lower animals, particularly the anthropomorphous or man-like apes, approach man very closely in bodily structure, they are nevertheless separated from him by a wide intellectual gulf. The brute is only in part a reasoning animal. Man is wholly so. The far-reaching intellect of man enables him clearly to perceive, not only his relations to external nature, but to his fellow-men and to his Maker. Man differs from all animals in this, that he has an improvable reason, an exalted moral nature, a knowledge of right and wrong, a distinct perception of the Deity, and a belief in a future existence. He also has the power of raising fire artificially. He is also distinguished by his slow growth, long infancy, and late puberty; by his body being in a great measure devoid of hair, and his not being provided with weapons of offence or defence. Man alone of all the animals speaks, laughs, and cries habitually. Speech, laughter, and weeping are, however, to be regarded as the offspring of an exalted, intellectual, moral, and emotional nature. Speech is the outcome of a reasoning faculty which asserts itself by natural sounds; and laughing and weeping are the outcome of an emotional nature affected by pleasure or suffering in our fellow-men. The faculty of speech and the power of laughing and crying are all referable to operations going on in the brain. We must think before we speak, and to laugh or cry implies the existence and the perception of pleasure or pain either in ourselves or in others.

[1] "Lectures on Physiology, Zoology, and the Natural History of Man." London, 1822.

REFLEX ACTION

In man and the higher animals three kinds of reflex action have been described by Dalton.

1. That occurring in the spinal cord.
2. That depending on the tuber annulare, and
3. That necessitating the co-operation of the cerebral ganglia or hemispheres.

1. Spinal cord reflex action consists in a nervous impression generated in the integument, transferred by the sensory nerves to the grey matter of the cord, where it is converted into a motor impulse, which is subsequently reflected along the motor nerves to the muscles. In cases of diseased or injured spinal cord in man, this act can be performed in the absence of sensation and consciousness. In the case of the frog it occurs even after the head is removed.

2. The second kind of reflex action, namely, that depending on the tuber annulare, differs from the first in necessitating a certain degree of conscious sensation. (This, strictly speaking, is not reflex action.) Thus the nervous impression conveyed from the integument to the spinal cord does not stop here. It travels upward to the tuber annulare, and gives rise to a conscious sensation, which is immediately followed by a voluntary act. In the second form of reflex action the nervous sensation must be actually perceived, and the act which follows must be voluntary in character. There is, however (and this is the peculiarity), no time for reason or reflection. The voluntary impulse follows directly upon the receipt of the sensation. If a morsel of food falls into the larynx, coughing is at once produced. In such instances we do not cough methodically or from forethought, but simply because the sensation produced by the crumb compels us to do so.

3. The third kind of reflex action requires the co-operation of the cerebral ganglia or hemispheres. (Here the conditions of true reflex action are altogether absent.) In this case the nervous impression travels to the cord, thence to the tuber annulare, and thence to the hemispheres or brain proper. In the tuber annulare the sensation is perceived, and when it reaches the hemispheres a train of ideas is generated. We know the source of the external impression, we perceive wherein it may be to our advantage or disadvantage, and act accordingly. The subsequent act is not only voluntary, it is also rational. "It does not depend directly upon the external sensation, but upon an intellectual process which intervenes between the sensation and the volition." It involves the conscious adaptation of means to ends, and in this respect differs from the first and second forms of reflex action.

It is obviously inaccurate to regard 1 and 2 as reflex in the literal or ordinary sense, and as the subject is one of great importance it will be useful to discuss it somewhat in detail.

At present much confusion exists as to what are voluntary and what are involuntary or reflex actions, and the confusion is not confined to man and the higher animals, but extends also to the lower and lowest animals, and, in a sense, to plants. Of course in plants and the lowest animal forms, where a nervous system, though suspected, has not yet been demonstrated, it is not possible in the present state of science to draw a hard and fast line between voluntary and involuntary reflex movements. Nevertheless it cannot be doubted that in the insectivorous plants (Venus's fly-trap, the sundew, &c.), which catch flies, beetles, spiders, &c., by means of associated and definitely co-ordinated movements occurring in their leaves and delicate hyper-sensitive hairs or tentacles, the preponderance of evidence is greatly in favour of the movements being at least semi-voluntary.

The insectivorous plants attain the same ends by slightly different means. Thus the bi-lobed leaf of Venus's fly-trap (*Dionæa muscipula*) is provided with six minute, highly sensitive hairs, which, being touched by insects, &c., settling on the leaf, the two halves are caused to close and imprison the intruders. The touching of the hairs occasions a folding of the leaf; which means that a sensation or its equivalent travels down the hairs into the substance of the leaf, where it is interpreted, and a general folding movement produced. There are plainly lines of communication between the hairs and the leaf itself. When the leaf is closed and the living prey captured, a digestive fluid, akin to gastric juice, is exuded by glands, which, after the lapse of a certain interval, liquefies and disintegrates the captives, and so prepares them for absorption and assimilation. The leaf remains closed, and firmly closed, until the act of digestion is completed; it then opens to receive a supply of fresh prey. All this is very remarkable, but a still more extraordinary procedure is to be noticed. If a non-edible substance falls accidentally, or is placed intentionally, on the leaf, the leaf closes, but it does not remain closed, and no digestive fluid is exuded. In Venus's fly-trap we behold a series of associated, definitely co-ordinated, vital movements—movements of the hard and soft parts of the leaf of the plant to a given end, movements obviously under control and in no sense haphazard. They are clearly not the product of irritability, external stimulation, or reflex action.

In the sundew (*Drosera rotundifolia*) the leaf is saucer-shaped, and bristles all over with slender and exceedingly sensitive hairs or tentacles. The tips of the hairs are covered with a clear, viscid secretion which attracts flies,

small beetles, spiders, &c. The secretion entangles the feet of the living, creeping things which find their way to the leaf. No sooner is the prey entangled than the hairs or tentacles bend, and, by a combined rolling movement, transfer the captives to the centre of the leaf, where they are firmly pinned down. A digestive fluid is then thrown out, and the tentacles remain resolutely bent until digestion and absorption are accomplished, after which they gradually unbend to catch fresh prey. If a plant be tricked by dropping tiny pieces of non-edible substances, such as cork, thread, hair, &c., on the leaf, the tentacles bend at first, but they soon after unbend, and no digestive fluid is poured out. In the sundew phenomena very similar to those occurring in Venus's fly-trap are witnessed. The tips of the sensitive hairs are touched, and convey an impression to their bases, and then to the glands of the leaf, which exude a digestive fluid. The curious thing is that the bending of the hairs does not begin at the tips (the point of contact), but at the bases, and the digestive fluid is not thrown out until the hairs are bent. The sensation or its equivalent passes into the substance of the plant and is then transmitted outwards to the bases of the hairs and the glands. Here, again, lines of communication of some sort are in evidence. We have, in fact, a remarkable degree of co-ordination in the hard and soft parts of the plant, and adaptation of means to ends. The trap is set and baited, the prey caught, imprisoned, crushed, and digested, and the process is repeated so long as the plant is in a state of health and is feeding. The plant distinguishes between edible and non-edible particles; it seizes, holds, absorbs, and assimilates the edible, and rejects and unceremoniously extrudes the non-edible.

If the plant were a conscious voluntary agent it could not do its work more expeditiously or effectively. It is difficult to deny to the sensitive plant a low form of cognition, and the power of voluntary movement.

The extreme sensitiveness of the tentacles to contact from without, and the ready response from within to a touch or impact; the power of closing and keeping the leaves and tentacles closed for days when insects are seized, or of opening them after a few hours when spurious pabulum falls or is dropped upon them; the ability to exude a digestive fluid wherewith to dissolve edible particles, and the power to withhold the said fluid when non-edible particles are placed on the leaves; all lead to the conclusion that it would be a mistake to regard the actions of insectivorous plants as either involuntary or reflex. The plants clearly possess and exercise a power of discrimination which is at variance with purely involuntary action. It might be argued that secreting and other glands and structures, in our own bodies, exercise similar powers and movements; each gland withdrawing from the blood a something which it converts into a peculiar secretion differing from every other secretion; the glands and other structures selecting their own pabulum from the blood while it pre-exists; the excreting glands depleting the blood of its waste products, &c. My reply is that the cases, although analogous, are not identical, and that all tissues which exercise a selective, discriminating power, and exhibit associated, co-ordinated movements must be accredited with the voluntary principle.

The varying results witnessed in the insectivorous plants are obtained apart from nerves and muscles as we know them, and the movements cannot be regarded as reflex, seeing the machinery, by which reflex movements in the higher animals are secured, is absent. If, however, movements nearly as definite and precise as those witnessed in animals having well-developed nerves and muscles can be obtained in plants and the lowest animal forms by protoplasm and rudimentary structures, it shows us how dangerous it is to attempt to limit the potentialities and possibilities of living matter, and to say this feels and that does not feel; this moves voluntarily and that moves involuntarily; this is conscious and that is unconscious; this thinks and that is incapable of thinking. Wherever adaptation and means to ends exist, the living things displaying the adaptation must be accredited with the power of adaptation apart from irritation and external stimulation. The living things which find their way to the leaves of insectivorous plants are objects to be secured as food, and the plants which, as it were, are lying in wait for them secure them in the most scientific and business-like manner. They feel their prey, close with it, and ultimately overcome and devour it.

The machinery by which this is done is very simple but very effective. In the sundew the main feature is the extraordinary sensitiveness of the hairs and tentacles. These are infinitely more sensitive than the most delicate nerves in our own bodies. According to Darwin the hairs of the sundew can feel, and be influenced by, the contact of bodies weighing less than $\frac{1}{78740}$ of a grain.[1] With such facts before us we should hesitate to regard plants as mere automata with no self-directive power.

In the amœba, composed of a jelly speck of protoplasm with, so far as known, no nervous system or differentiation of any kind, voluntary movements undoubtedly take place. This animal can cause any part of its body to move in any direction, either to seize food or to escape from danger. When food is encountered a portion of the body is thrown over it, and the portion the food touches becomes a temporary stomach for its absorption and assimilation. The amœba, like the insectivorous plant, can extrude and avoid non-edible particles. The amœba, with no nerves, no muscles, no glands, or any of those structures or substances with which we associate voluntary

[1] "Insectivorous Plants," by Charles Darwin, M.A., F.R.S. London, 1875, p. 33

movements, can nevertheless move at will, and discharge all the vital functions necessary to an independent being. It can go where it pleases, can seize edible and avoid non-edible particles, can grow and reproduce itself, &c. The potentialities of living matter, in the present state of science, cannot be gauged. Similar remarks are to be made of hundreds and thousands of low animal forms, such as the animalcules, and the infinite multitude of microbes which swarm everywhere.

One has only to examine a drop of water with the microscope to be convinced that the rudimentary denizens of that fluid, however they may vary in size and shape, are all masters of the situation, and move voluntarily and to given ends. They dart about and curve and wheel in endless combinations, but they steer clear of each other, and never collide unless with the object of reproduction, or of devouring one another. One of two things follows: either there is a diffuse, semi-fluid nervous system, which cannot be demonstrated, or a nervous system is wholly absent. If the latter, then what are practically voluntary movements can take place without a nervous system. Neither nerves nor muscles, in a differentiated form, are necessary to voluntary movements in the widest sense. If this be so, it requires no great stretch of the imagination to associate voluntary movements with the higher plants on the one hand, and with the lower animal forms on the other. Simple undifferentiated or very slightly differentiated living matter can apparently exert powers which have hitherto been claimed, but erroneously claimed, for the higher animals alone.

The corollary is obvious :—

(*a*) The equivalents of nerves and muscles apparently exist in a non-tangible form in all living matter (however shaped and circumstanced), in plants and the lower animals, and in the tissues of the highest animals, which enable them to act independently and to given ends.

(*b*) The powers inhering in living matter can be and are exercised apart from irritation and external stimulation.

(*c*) A nervous system, even in the highest animals, is not necessary to the due discharge of the vegetative functions of the said animals.

(*d*) The primary or fundamental movements, especially the rhythmic movements, in the higher animals, are not caused, but only regulated, by the nervous system.

(*e*) The movements in question are not reflex movements, in the ordinary sense.

(*f*) The highest plants and lower animals, and all living tissues, are to be accredited with powers of self-movement, self-regulation, and self-adjustment and adaptation which make them superior to their surroundings and enable them to act as independent entities.

(*g*) Division of labour in the highest plants and lower animals, and in all tissues, is carried on apart from nerves in the higher and ordinary sense; each living unit being accountable for its own quota of work.

(*h*) All living things, whether plant or animal, are to be regarded as sentient moving masses—the powers of feeling and moving residing in all the atoms and particles of plants and animals.

(*i*) It is a mistake to refer all feeling and movement in plants and animals to the operation of a nervous system, if it does not pervade all living matter and every part of every tissue of plants and animals.

A question of great importance emerges here. Is modern physiology prepared to assign to living matter, as witnessed in the higher plants and lower animal forms, and in the tissues, a just measure of spontaneous and independent movement and self-control, or are the simple organisms, plant and animal, which living matter forms, to be regarded as mere automata with no initiative, and which only move when they are goaded into activity by external stimuli, in a reflex manner, and involuntarily? I prefer the former alternative as the best mode of escape from the horns of a dilemma.

Movements hitherto attributed to reflex action may in reality be direct, spontaneous, and independent movements. To take examples: the movements of the heart are said to be reflex movements due to irritability and the stimulation caused by the inflow of the blood into its several compartments; the blood acting upon the terminal nerves and ganglia of the organ, the nerve being primarily furnished by the cerebro-spinal and sympathetic systems. The reflex theory of the heart's action presupposes ganglia and a sensory and motor supply of nerves for the heart. There are very serious objections to the theory :—

(*a*) The heart of the chick beats and acts rhythmically before it contains blood and before it is supplied with nerves and muscles. The vacuoles in certain water plants (the *Volvox globator*, for example) do the same. The machinery on which reflex action is said to depend is in these cases wanting.

(*b*) The heart beats when removed from the body, when its main nerve supplies are cut off, when it is deprived of blood, and even when it is placed in an exhausted receiver: the supposed irritation and the mechanism believed to be necessary to the reflex movements are in this case non-existent.

(*c*) There is no proof that the interior of the heart is irritable and requires to be stimulated to do its work in

a reflex manner. Chauveau introduced small caoutchouc bags into the compartments of the heart of the horse without interfering in any way with the cardiac movements. This experiment gets rid of the theory of irritability and artificial stimulation. If reflex action produced one movement of the heart, say the closing of the left ventricle, it certainly could not produce the opening of the same part of the heart immediately after; the closing and opening movements being diametrically opposed to each other. There is, moreover, the fundamental difficulty as to the nature of the cardiac movements. They are rhythmic and constantly recurring movements. Reflex movements are not necessarily recurring or rhythmic in character. What is said of the cardiac movements applies equally to those of the alimentary canal, the stomach, and their sphincters; to those of the bladder and its sphincters; to those of the uterus and its sphincter, &c. All these movements are said to be reflex movements. The food is said to supply the stimulus for the movements of the alimentary canal and its sphincter, the urine for the bladder and its sphincter, and the fœtus for the uterus and its sphincter.

It is necessary to point out in this connection that the heart, stomach, bladder, and uterus are *receiving* and *retaining* structures as well as *discharging* and *propulsive* structures, and that their contents could not possibly be bland and non-irritating the one instant and highly irritating and stimulating the next. If the theory of irritability and artificial stimulation were correct they would require to perform this impossible rôle.

All the difficulty and confusion which at present exist as regards rhythmic and various other movements are due to the non-recognition of the fundamental powers inhering in living matter, and to the erroneous modern belief that all the tissues are irritable, and that they can only be made to act directly by volitions, or indirectly by reflex actions brought about by external stimulation. The tissues can and do move of themselves, apart from irritability and artificial stimuli. A volition may cause voluntary muscles to move, but the involuntary muscles move independently of volitions, and even apart from reflex action. There is no such thing as irritability in living things, and external stimulation is a physiological bogey invented to prop up an erroneous theory.

The respiratory movements are also said to be due to reflex action. The reflex hypothesis is even less satisfactory in this case. The argument is as follows. The interior of the lungs is said to be irritable, and the atmospheric air and an acid (described by Verdeil as " pneumic " or " pulmonic " acid) are supposed to act as stimuli. The presence of ganglia and of sensory and motor sets of nerves is taken for granted. With these conditions and appliances reflex rhythmic movements are believed to be produced, and no other explanation of the movements of the chest is forthcoming at the present day. The inherent, independent movements of the muscles of the chest, diaphragm, and abdomen, as of the heart, stomach, bladder, and uterus, are entirely ignored. There is, however, no proof that the interior of the lungs is irritable, or that the air and " pneumic " acid act as stimuli and produce motion—especially the interrupted rhythmic movements which characterise respiration.

It is the rhythmic nature of the movements of the chest, as of the heart, which supplies the stumbling-block over which modern physiology trips. If the interior of the lungs be always irritable, and the stimuli of the air and " pneumic " acid are always present, then there would be either one long closing movement, or one long opening movement, with intervals between, of the chest and lungs; there could not possibly be both, and a recurrence of both, so long as life lasts. The alternate and opposite movements, with pauses at stated intervals, which constitute a rhythm, cannot be accounted for by the conditions specified above. We must go deeper. Rhythmic, recurring, interrupted movements cannot be accounted for by a continuing irritability of the tissues, or by any constant form of stimulation, or by both combined. They must occur spontaneously in the sarcous or primitive elements of the muscles themselves at irregular intervals, and be regulated, within limits, in the higher animals by the nerves.

My own belief is that the sarcous elements of the cardiac muscles, and of the muscles of the chest, diaphragm, and abdomen, which take part in the respiratory movements, act rhythmically because of original endowment, and as a necessity of life in the higher animals. That the sarcode or protoplasmic portions of muscle can act rhythmically and apart from nerves is, I think, proved by the rhythmic movements of the vacuoles of water plants, which open and close with time-regulated beats in the absence of nerves.

There is no getting behind the rhythmic movements as witnessed in the heart, chest, stomach, bladder, uterus, &c. The rhythms are to be regarded as fundamental factors in physiology. Rhythms are necessary to the building up and disintegrating of all parts of plants and animals, and plants and animals cannot exist as apart from rhythms. The rhythms, for the wisest of purposes, are not to any extent under control. They go on from the dawn of life to its close without let or hindrance.

Other rhythmic movements said to be reflex in character may be noted. Thus the movement of swallowing is said to be due to the irritability of the interior of the œsophagus and the bolus of food acting as a stimulus. As a matter of fact the œsophagus, like the heart, is endowed with independent rhythmic movements, and the double power of opening and closing. When the bolus enters the œsophagus it is at once seized and transmitted in the direction of the stomach by a series of peristaltic movements similar to what occurs in the intestines. The

œsophagus is a living structure expressly formed to convey the dead food into the stomach, and this it does by alternately opening in front of the bolus and closing behind it. According to the prevailing reflex theory of the action of the œsophagus, the bolus acts as a stimulus, and causes the swallowing movements. Now if this were so the bolus would cause contraction of the muscular walls of the œsophagus in front where it touches and not behind. It would, moreover, not occasion the opening and closing, peristaltic, rhythmic movements which alone can secure its transmission. The question at issue here, as in the heart, chest, &c., is as to whether living structures are to be credited with inherent independent movements to given ends at first hand, or whether living structures can only move when in an irritable condition, and when pricked into activity by extraneous living or dead matter. I accept and strongly support the former view.

Winking is also said to be due to reflex action. That winking is a direct vital act inhering in the structures which produce it is abundantly proved by this, that it is rhythmic in character, and only occurs during the waking hours. It cannot be the light or darkness which produces it, as one may sleep either during the night or day.

The movements of the iris and the opening and closing of the pupil are said to be due to reflex acts. Here the old difficulties recur. The intensity of the light is said to regulate these movements, but the cart, as is usual, is put before the horse. The varying light—the dead thing—is said to open wide or partially close the pupil or aperture of the iris of the eye. The elaborate and daintily-constructed iris, with its living, radiating, and circular muscular fibres, expressly formed to measure the amount of light admitted to the eye, is ignored, and the light, plus the nerves of the iris, is regarded as the prime mover. The non-living thing is made to determine the movements of the living thing; that living thing being as expressly formed for measuring the intensity and quantity of the light as the eye is itself for recognising the light and the objects, near and far, which the light reveals.

The phenomenon of blushing is also set down as a reflex act. No better example, however, of a direct act could be given. Blushing is in every instance due to mental emotion, the mind acting on the motor nerves investing the smaller arteries.

The various so-called reflex acts involved in nutrition and growth, absorption and assimilation, secretion and excretion, reproduction, &c., may all be explained, apart from irritability and external stimulation, by simply assigning to the structures concerned their inherent independent powers of discrimination, selection, movement, &c. The child breathes as soon as born; it also sucks. The breathing and sucking structures are both formed before the rhythmic movements which constitute breathing and sucking are inaugurated.

These and other normal rhythmic movements, such as winking, coughing, sneezing, &c., are all provided for in the organism itself. Even abdominal rhythmic movements, such as stammering, chorea, the see-saw motions made by imbeciles, &c., have their origin in the tissues of the organism.

There is no need to assume in living organisms, capable of acting at first hand, an indirect, reflex, or second-hand mode of procedure, especially when that procedure involves the existence of a set of extraneous, artificial conditions, which I venture to state do not exist, and cannot be demonstrated.

The whole question of movement in plants and animals requires revision from the vital as distinguished from, and opposed to, the mechanical point of view.

It becomes a question whether in the higher animals there is any such thing as a reflex act. Reflex acts certainly do not exist in plants and the lower and lowest animals, and for the very good reason that the nerves and muscles which are necessary to their production do not exist. When, however, nerves and muscles (the machinery required for reflex action) are actually present, there is still a preliminary point of great importance to settle. The so-called reflex acts are in every instance associated, co-ordinated movements, and there are good grounds for believing that they were originally, each and all, direct movements; that is, movements inhering in the tissues exhibiting them; those movements being fundamental and vital, and in no sense depending upon irritability or extraneous stimulation. These associated, co-ordinated movements, which I regard as fundamental and necessary to life, are the result of original endowment, and of infinite repetitions from the earliest periods of plant and animal life. The plant known as *Volvox globator* opens and closes its vacuoles without ceasing, and the heart of the chick, where no nerves or muscles exist, and before it contains blood, does the same. The endless repetitions in the latter case are in no way altered by the actual presence of nerves and muscles in the heart of the adult fowl. Nerves and muscles are not necessary to rhythmic movements; the fundamental and important point is the recurrence and repetition of the movements at stated intervals. The rhythmic movements so well seen in the involuntary muscles of the heart are repeated in the involuntary, mixed, and voluntary muscles of the chest, diaphragm, and abdomen. Here there is a transition from involuntary muscular action to mixed and voluntary muscular action; the character of the action, which is rhythmic, remaining. The transition is simple and natural. The rhythmic movements which in the case of the heart take in, retain, give out, and circulate the blood, in the case of the chest take in, retain, give out, and circulate the air. The stomach and alimentary canal in like manner take

in, retain, circulate, and give out food; the bladder and the uterus do the same for the urine and the fœtus. One law applies to all, and it is the law of endless repetition. When by constant repetition a habit has been formed in muscles, or nerves, or both combined, it suffices if any part of the mechanism producing the associated movements is set in motion. The other parts at once join in and assist. In mental acts, say the associated movements of the molecules of the brain which constitute memory, one thing recalls another; hence the doctrine of the "association of ideas."

These associated, co-ordinated, fundamental movements, which are indispensable to life, are, as explained, not confined to the involuntary muscles as we behold them in the hollow viscera. They extend to the chest, where voluntary muscles are found, and this explains why the respiratory movements, which are essentially and fundamentally involuntary, can be controlled for brief periods by an effort of will. As a matter of fact the rhythmic movements occurring in a typical form in the involuntary muscles merge into what may be accurately designated rhythmic movements in the voluntary muscles. The movements of the voluntary muscles are in every instance, or very nearly so, associated, co-ordinated movements. They are original endowments in the young and immature individual, but are perfected by repetition and training in the adult individual to quite an extraordinary degree. The very essence of training consists in constant and endless repetition at recurring intervals, and what at one time required a concentrated and direct effort of will, by-and-by requires no effort at all.

The associated, co-ordinated, *involuntary* movements are to be regarded as the parents of the associated, co-ordinated, *voluntary* movements. These movements in walking, swimming, and flying furnish examples. In young animals the germs of these movements exist; they are developed in adult animals. Quadrupeds and bipeds require to learn to walk, fishes and beasts to swim, and insects, bats, and birds to fly. When the art of walking, swimming, and flying has been duly acquired—that is, when the muscles and parts involved have been duly trained, and the associated, co-ordinated movements involved perfected—no mental effort whatever is necessary. The movements of walking, swimming and flying are associated, co-ordinated, rhythmic movements in all respects similar to those of the heart and chest. What is here said of the associated, co-ordinated movements involved in walking, swimming, and flying, applies to all other kinds of associated, co-ordinated, muscular movements where perfection is attained by repetition, such as leaping, skating, curling, riding, wrestling, fencing, boxing, dancing, golfing, rowing, cricketing, playing football: all manner of games and sports, and all manner of occupations and handicrafts. As the old adage has it, "Practice makes perfect."

In my remarks upon associated, co-ordinated, rhythmic muscular movements, involuntary and voluntary, I have purposely made no reference to the nervous system, for two reasons:—

(*a*) Because these movements can and do occur in plants and in the lowest animals, where, so far as we know, no nerves are present; and,

(*b*) Because the nerves do not cause the movements, but merely assist in regulating them.

I may further add that the nerves and muscles, when both are present, share and share alike in their production; the nerves and muscles being equally amenable to education and training. It is a common and a correct saying that "good hands must have a good head behind them." As a matter of fact, structure and function always go together. Wherever large groups of associated, co-ordinated movements occur, the nerve centres and nerves connected with them acquire large dimensions and increased importance. This remark applies to the nerve centres and nerves in the brain, in the spinal cord, and elsewhere. In such cases the supply of blood to the muscles, the nerves, and nerve centres is very largely augmented.

From the foregoing it will be evident that the so-called reflex or indirect movements are at the outset direct movements, and that they only become reflex, indirect, and involuntary after endless repetition either in the individual or in the ancestors of the individual. This view adequately explains the so-called instinctive acts, the habits of animals, the migratory flights of birds, &c. It could not be otherwise. All living things are face to face with the external world, and they are expressly fashioned and endowed to deal with nature directly and at first hand. The roundabout mechanism of reflex action is contra-indicated.

The remarks which follow, on unconscious cerebration, are simple expansions of the opinions now stated.

§ 228. Unconscious Cerebration.

Unconscious cerebration may be defined as an automatic mental act produced, without any effort of will, by the mere force of habit or repetition. It may give rise to a great variety of complicated muscular movements, such as those involved in walking, swimming, flying, performing on musical instruments, &c.

To acquire the movements in question, frequent and laborious efforts are indispensable, but when once acquired they can be performed automatically and without thought. It is necessary to creep before we walk, but when we

get the length of walking we do not require to think about or will to walk. We can trundle along at a good pace, and chew the cud of reflection without fear of falling.

The story told by Huxley of the old soldier carrying his dinner along Fleet Street affords a good example of unconscious cerebration. He was met by his old commanding officer, who shouted in his ear, "Stand at ease!" Down went his hands, and his chop and potatoes were landed in the gutter.

The movements resulting from unconscious cerebration greatly resemble the involuntary ones.

In some cases, where the mind has become affected, the rhythmical character of the movements is reproduced. Thus, in visiting lunatic asylums, I have observed imbeciles giving to their limbs and other parts of their bodies see-saw or rhythmic movements in all respects resembling involuntary ones. When the brain acts unconsciously, and when the mind is diseased, the rudimentary, involuntary movements which occur in the viscera (heart, stomach, lungs, &c.) occur in the limbs and other parts of the body.

The see-saw movements referred to are occasionally to be witnessed in the so-called "weaving" movements of animals. A horse, for example, sometimes keeps tossing its head in a to-and-fro fashion to the great discomfort of the rider, and animals in menageries, particularly the carnivora, move backwards and forwards in their cages without ceasing.

§ 229. Phrenology in Relation to Cortical Brain Areas.

Phrenology on a superficial examination has many things to recommend it; on a more careful examination it presents numerous difficulties. This remarkable physiological doctrine was originally advocated by Gall and Spurzheim. These investigators recognised the fact that the intellectual powers are seated in the brain, and that the brains of man and animals increase in size according to the degree of intelligence. They further observed that dissimilar functions are performed by different parts of the nervous system in various portions of the body. Proceeding on such general grounds, they came to the conclusion that different parts of the brain discharged dissimilar functions, and that all that was necessary to localise these functions, and to form a chart of them, was to examine the heads of individuals noted for mental peculiarities in specific directions. With such a chart it was believed that, even by an examination of the external configuration of the head, the peculiar mental characteristics of an individual might be satisfactorily made out. Phrenology, true up to a point, is defective from failing to deal with all the facts.

Gall and Spurzheim only mapped out and differentiated the superior, lateral, and antero-posterior external surfaces of the brain. These, however, represent only about a fourth of the entire brain surface. They did not map out the whole of the under surface of the brain, the surfaces corresponding to the space between the cerebrum and cerebellum, the surfaces corresponding to the great longitudinal fissure of the brain, and those corresponding to the sylvian fissures and the convolutions.

They further failed to note that there is a want of correspondence between the surface of the brain and the external configuration of the head.

The skullcap is occasionally thickened in parts—a projection or bump appearing externally, and being accompanied by an actual want of brain substance interiorly. Finally, they attributed certain mental traits to the frontal sinuses, which, as anatomists know, only contain air.

Akin in some respects to the phrenological theory advanced by Gall and Spurzheim is that propounded by Fritz and Hitzig, and more fully developed by Ferrier.

Fritz and Hitzig, by passing electrical currents through various parts of the brains of dogs, came to the conclusion that the anterior parts of the cerebrum are motor in their nature—the posterior parts being non-motor. They are also of opinion that single psychical functions, and probably all, are referable to *circumscribed centres of the cortex of the cerebrum.*

Ferrier's views deserve careful attention. This investigator employed Faradisation exclusively in his experiments.

Ferrier did not succeed in obtaining definite results from the brains of birds. He experimented principally on mammals, such as the guinea-pig, rabbit, cat, dog, monkey, &c. He applied his electrodes, or points conveying the electricity, to definite areas of the brain substance, with the following results :—

1. The anterior portions of the cerebral hemispheres are the chief centres of voluntary motion and the active outward manifestation of intelligence.

2. The individual convolutions are separate and distinct centres; and in certain definite groups of convolutions (to some extent indicated by the researches of Fritz and Hitzig), and in corresponding regions of non-convoluted brains, are localised the centres for the various movements of the eyelids, the face, the mouth and tongue, the ear, the neck, the hand, foot, and tail. Striking differences, corresponding with the habits of the animal, are to be found

in the differentiation of the centres. Thus the centres for the tail in dogs, the paw in cats, and the lips and mouth in rabbits, are highly differentiated and pronounced.

3. The action of the hemisphere is in general crossed, but certain movements of the mouth, tongue, and neck are bilaterally co-ordinated from each cerebral hemisphere.

4. The proximate causes of the different epilepsies are, as Dr. Hughlings Jackson supposes, "*discharging lesions of the different centres in the cerebral hemispheres.*" The affection may be limited artificially to one muscle, or group of muscles, or may be made to involve all the muscles represented in the cerebral hemispheres, with foaming at the mouth, biting of the tongue, and loss of consciousness. When induced artificially in animals, the affection as a rule first invades the muscles most in voluntary use.

5. Chorea (St. Vitus's dance) is of the same nature as epilepsy, dependent on momentary and successive discharging lesions of the individual cerebral centres.

6. The corpora striata have a crossed action, and are centres for the muscles of the opposite side of the body. Powerful irritation of one causes rigid pleurothotonus, the flexors predominating over the extensors.

7. The optic thalamus, fornix, hippocampus major and the convolutions grouped around it, have no motor signification, *and are probably connected with sensation.*

8. The optic lobes, or corpora quadrigemina, besides being concerned with vision and the movements of the iris, are centres for the extensor muscles of the head, trunk, and legs. Irritation of these centres causes rigid opisthotonus and trismus.

9. The cerebellum is the co-ordinating centre for the muscles of the eyeball. Each separate lobule (in rabbits) is a distinct centre for special alterations of the optic axes.

10. On the integrity of these centres depends the maintenance of the equilibrium of the body.

11. Nystagmus, or oscillation of the eyeballs, is an epileptiform affection of the cerebellar oculo-motorial centres.

The experiments of Fritz, Hitzig, and Ferrier, especially the last, establish beyond doubt that certain areas of the cortex of the brain act as nerve centres for certain muscular movements in different parts of the body, and that these nerve centres can be influenced from without much in the same way that the sensory nerves all over he body can be influenced by applying stimuli to the skin. It follows from this that the brain, like other parts of the body, has its sensory and motor nerves; these two kinds of nerves being connected with each other by means of nerve cells, ganglia, neurons, &c. Nor could it be otherwise. The brain, as I have already explained, is a modification and expansion of the elements composing the spinal cord, just as the skull is a modification and expansion of the bones forming the vertebral column.

The peripheral or sensory nerves of the brain, as I have pointed out, are diminished in volume and dulled by disuse because of the intervention of the bones of the cranium between them and the integuments of the head. The cranial sensory nerves nevertheless exist, and can be acted upon from without, as other sensitive nerves in different regions of the body can be acted upon. They can also, because of their connection with the nerve cells, ganglia, neurons, &c., directly or indirectly influence the motor nerves and the muscles which the latter set in motion. From what is here stated it will be seen that I am opposed to the oft-repeated dictum that the brain is wholly insensitive and inexcitable. If it were so it would form an extraordinary exception to nerve matter in all other parts of the body.

§ 230. Nerve Endings in the Brain, Skin, and other Structures.

Much discussion has arisen on this important subject, and it is one of great interest from the fact that it is intimately and directly connected with sensations, perception, volition, and other brain manifestations. The following is the account given by Dr. Lionel S. Beale:[1] "In peripheral parts, it seems to me certain that the general principle of the arrangement of the finest ultimate nerve fibres is that of continuous conducting cords or fibres, which are *endless*, and, as I believe, invariably form uninterrupted circuits. In all cases, the matter of the fibres is closely connected at intervals, which vary in extent in different parts and organs, with bioplasts, or particles of living matter, by which the fibres were formed, and upon which their *actions* through life entirely depend. The general arrangement, as far as I have been able to ascertain, in nerve centres is on the same plan and according to the same principle—every ganglion 'cell,' and every brain and spinal cord 'cell,' having *more* than one fibre emerging from it, all the fibres passing towards or joining others, which extend from the centre to the peripheral nerve networks. Indeed, the nerve centre may almost be regarded as a peripheral arrangement, collected, as it were, and arranged to occupy as little space as possible, instead of being spread over large areas of surface.

"Every voluntary and involuntary muscular movement, and every impression on nerves or organs of sensation,

[1] 'Vitality." London, 1899.

and, as I believe, every expression of thought, involves the direct simultaneous action of several thousands of minute bioplasts, which in *every* peripheral nerve distribution, in *every* sense organ, and in *every* nerve centre of man and vertebrata are innumerable.

"What is particularly striking, is the comparatively long distance between the peripheral and central nerve 'cells,' which in all cases are, as is well known, connected by nerve fibres, in the long course of which there is no break or interruption of any kind. Nowhere can I find evidence of any part of the nerve thread being connected with, or forming an integral part of, any other tissue. I have never seen an end of a nerve, or discovered a gap, and I must regard the central and peripheral bioplasts as being intimately connected by continuous fibres constituting a complete circuit, which I have reason to believe is the typical arrangement of every nervous system.

"The idea of any kind of nerve apparatus beginning life as a centre from which fibres are afterwards shot out, or extended, or caused to grow, towards distant parts of the body, is not tenable. There is not to be found a ganglion 'cell,' or other nerve 'cell,' or a nerve centre, which is unconnected with other 'cells,' ganglia, or centres. Nor is there a nerve cell with *less than two fibres*, which pass away from it in opposite directions. In some ganglion cells in which one fibre, as it leaves the cell, is coiled spirally round the other, the two fibres proceed in opposite directions a short distance from the cell, with which both are intimately connected, one with the central, the other with its circumferential part (see Plate cxxxv., Fig. 4, A and B, p. 756).

"That the grey matter of the cerebral convolutions of man and many mammalia comprises, besides many centres of sensation, centres not only of muscular movements, but of associated and combined movements, of particular muscles and parts of muscles, has been proved beyond all question in recent years by the excellent work of many physiologists, and especially by the well-known researches of my colleague, David Ferrier. These 'centres' are connected with others in different parts of the brain, and nervous system, by communicating fibres.

"The very fine fibres I have seen in the intervals between the so-called 'nerve cells' in the cortical part of the brain in vertebrata, and which are innumerable, may be traced as they divide and subdivide, radiating in different directions from the cell; and although it is almost certain that here and there adjacent cells are connected even in mature organisms, and perhaps many thus form small groups, by far the greater number of fibres pursue a long and frequently tortuous, but seldom perfectly straight, course in various directions, so that it is only possible in very few instances to follow a single fibre even for the hundredth of an inch, in the complicated course it pursues between adjacent 'cells' in the cortex of the brain.

"Of this all-important cortex, I am here referring to the character of only a very minute portion, in fact, less than the one-thousandth of an inch in diameter; but the same general arrangement exists in other parts of the cortex."

Beale regards the nervous system as originally formed from bioplasm (which, according to him, is a clear, watery, structureless, living substance); that it consists of nerve cells, ganglia, brain, and conducting fibres, sensory and motor; that the nerve substance is continuous, and forms circuits through which nerve currents may be passed; and that there are no such things as nerve endings, but only loops of continuous plexuses.

Beale's views as to nerve endings have lately been opposed by Sir W. Gowers, who, relying upon Golgi's new process of nerve preparation, maintains that "We have in every axis cylinder a bundle of separate conducting fibres, and we have those fibres passing uninterruptedly through the nerve cells in the branching processes and ending at the terminations of the branches" (Plates cxxvii. to cxxx., pp. 742 to 747 inclusive).

Gowers adds, we must once for all give up the idea that "nerve cells" are sources of "nerve impulses."[1] The branching processes—"dendrons" or "dendrites," as they are called—terminate, according to Gowers, in a "ground substance or matrix."

Similar nerve arrangements and endings are figured by Professor Schäfer in the last edition of Quain's "Elements of Anatomy"[2] and in Biederman's "Electro-Physiology."[3]

The new views as to nerve endings, &c., in Beale's opinion, militate against the generally accepted doctrine that nerve cells and nerve ganglia are independent centres capable of receiving impressions by the sensory nerves from the skin and converting them into motor impulses to be sent out by the motor nerves to the muscles, &c.

These apparently hostile views are not necessarily irreconcilable. Nerve centres may receive sensory impressions from without and transmit motor impulses from within even although the sensory and motor nerves pass through the nerve cells and ganglia; the latter being situated upon and taking advantage of what are practically *through nerve routes*. A ductless gland influences and changes the character of the blood which passes through it, and nerve cells and ganglia placed on nerve tracks may influence and change nerve currents passing through them, either from the periphery inwards or from the sensorium outwards. There is no actual necessity for nerve fibres *terminating*

[1] "The Neuron and its Relation to Disease" (*British Medical Journal*, November 6, 1897).
[2] Vol. i., part ii.
[3] Macmillan & Co., 1898.

in nerve cells and ganglia. Neither is there any need for the sensory and motor nerves terminating in loops and plexuses rather than in free ends, nerve bulbs, Pacinian bodies, dendrons, &c. On the contrary, if the doctrine of nerve endings at the periphery and dendrons or dendrites at the sensorium be accepted, a puzzling anomaly will be removed.

It has long been known that the large caudate cells in the cortex of the brain end in free extremities which are directed outwards—that is, towards the interior of the skull. The nerve endings in question are, as a matter of fact, peripheral nerve endings analogous in all respects to the peripheral nerve endings found everywhere on the surface of the body. The nerve endings referred to are modified and aborted because the hard skull prevents the transmission of sensory impressions from without, and so begets disuse and the impairment of structure and function which disuse entails. That the impairment of the sensitive properties of the cerebral nerve endings is not complete is proved by the fact that the motor machinery of the nervous system can be set in motion by stimulating certain areas of the cortex of the brain.

The circumstance that groups of muscles can be set in motion by stimulating, after the manner of Fritz, Hitzig, and Ferrier, different parts of the cortex of the brain, goes far to prove the sensory nature of the free endings of the caudate cells to which allusion has been made.

But (and this is important) the efficiency of the nervous system is equally secured by both arrangements, either the distribution of the finest nerves in loops and continuous plexuses in the skin, muscles, brain, &c., or the distribution in free ends, end bulbs, Pacinian bodies, nerve plates, and dendrons.

As far back as 1872 I showed that the motor nerves could be influenced, and groups of muscles brought into action, by artificially stimulating either the skin or the surface of the cortex of the brain. I pointed out that the surface of the brain had its sensory nerves (dulled by disuse), and that these were directly or indirectly connected with motor centres in the brain, in the same way that the sensory nerves in the skin were connected, directly or indirectly, with motor centres in the spinal cord: that, as a matter of fact, the brain was an expansion of the spinal cord, and that the latter contained all the elements to be found in the former in a slightly more rudimentary and less elaborated form. This view, I maintained, was strongly supported by the anatomy of the brain, and by analogy (see Plates cxxx. and cxxxiv., pp. 747 and 754).

Oken and Goethe long ago showed that the skull was composed of modified vertebræ, and I argued that the reasoning employed by them with regard to the skull applied with equal cogency to the brain, or skull contents. The analogy, I contended, was so obvious that it only required to be stated to be accepted. I was then ignorant of the existence of dendrons in the brain, in their modern acceptation, but I clearly indicated my belief in the existence of such structures, and of the necessity for them in explanation of the fact that the motor nerves, and the muscles to which they are distributed, may be influenced by direct stimulation of the skin by tickling, &c., or by stimulation of the cortex of the brain by galvanism, &c.

The sense organs concerned in feeling, tasting, smelling, hearing, and seeing are clearly peripheral nerve structures; they are, in fact, highly differentiated sensory nerves which issue from and centre in the brain (see Plates cxxxvi. to cxlii. inclusive, pp. 757 to 766). If this be so, it need occasion no surprise if the brain itself possesses other sensory nerves or nerve endings, which are in a way *undifferentiated*, and the action of which is to a large extent impaired by disuse.

A few words, by way of recapitulation, on the structure and uses of the spinal cord in the higher vertebrates, especially man, will be useful in this connection.

The human spinal cord, as already explained, consists of white and grey nerve matter, the white being external to the grey. In the brain this order is reversed, the grey matter being found on the surface and convolutions of the cerebrum, the white matter occupying a deeper and central position. In the spinal cord the grey matter consists of a double concentric column, the free margins of the column being known as its horns. The white matter is arranged in six vertical columns to the outside of the grey columns. They are known as the two anterior, two posterior, and two lateral columns (see Plates cxxxi., cxxxii., and cxxxiii., pp. 749, 751, and 753). The cord is double in the sense that it is divided into two nearly symmetrical portions by the anterior and posterior median fissures. The structure and function of the grey and white matter are very different. The grey matter, for example, consists very largely of nerve cells and nerve ganglia, to which are attached conducting nerve fibres; while the white matter is composed almost exclusively of conducting nerve fibres. Functionally the grey matter (of the cord) receives sensory or afferent nerves from the skin, and sends out motor or efferent nerves to the muscles. The anterior portions of the cord, as a whole, are motor, the posterior portions sensitive. The grey and white nerve matter of the cord throughout its whole extent is continually receiving sensory and giving off motor nerves. Its several parts are connected vertically by nerve fibres; they are also connected transversely by nerve fibres and nerve commissures, both of the grey and white matter. The vertical nerve fibres connect the different parts of the cord with each other and

also with the brain. The transverse nerve fibres and commissures connect the two symmetrical halves of the cord with each other, and also the various nerve cells and ganglia found in each half of the cord. The cord can transmit sensory impressions to its several parts, and to the brain; it can also send motor impulses to its several parts, and to the muscles. The sensory impressions and motor impulses may be confined to the one half of the cord and brain, or they may travel across the cord and brain to the other or opposite half. The cord and brain very frequently discharge the crossed function. The anatomy of the cord corresponds with the anatomy of the vertebral column: thus a set of sensory and motor nerves enter and leave the cord between every two vertebræ on either side. The cord in this sense is segmented as the vertebral column is segmented. It exercises a general control over the voluntary movements of the trunk and extremities.

The brain is to all intents and purposes an expansion and elaboration of the spinal cord. The first expansion is the medulla oblongata, the second the cerebellum or little brain; the third is the cerebrum or great brain, composed of two symmetrical halves or hemispheres, which are known as the cerebral lobes. These lobes are composed of grey and white matter—the white being inside, the grey on the surface. The grey matter is crowded with nerve cells, ganglia, neurons, &c.: the white matter being composed of conducting fibres, sensory and motor. The surface of the brain in the higher animals, especially man, is richly and deeply convoluted; the convoluted arrangement very greatly increases the area of the grey matter, which is the most important part of the brain. The two halves of the brain are united to each other at various parts by transverse nerve fibres and commissures. The convolutions are similarly united; the brain as a whole exerts a vertical, oblique, and crossed action.

The sensory nerves and sense organs are not to be regarded as isolated portions of the nervous system. On the contrary, they are connected, directly or indirectly, with nerve cells, ganglia, and other structures, and, through them, with the motor nerves which produce, or may produce, muscular and other movements. The possession of sensory nerves and sense organs would be a barren one if it did not or could not culminate in action. The sensory and motor nerves and the intermediate nerve cells, ganglia, &c., form parts of a whole, and are to be considered together. Action may or may not follow on receipt of a sensation, but the machinery for producing motion is always present. This is necessary for the convenience and protection of animals. A living animal must move in search of food; it must also be provided with the means of escape in case of danger; the sensory nerves and sense organs give information regarding the external world, and it is for the brain or its homologue, with the motor nerves and muscles, to take advantage of the information conveyed.

It is a matter of no great importance physiologically whether the nerves terminate in loops or plexuses, or in free ends, end plates, bulbs, or dendrons. It is sufficient to know that the sensory nerves extend to all portions of the skin, mucous membranes, &c., and that the motor nerves extend to the muscles, glands, and other structures to which they are accredited. There is every reason to believe that the touch corpuscles in the skin and the dendrons in the brain are analogous structures, and, within limits, discharge similar functions. Both may not inaptly be compared to electrodes by the aid of which nerve currents can be transmitted from the periphery to the centre. In the case of the brain, dendrons with their nerve cells and ganglia can not only transmit *but generate nerve impulses.* These impulses may be voluntary or involuntary. When voluntary they are known as volitions, and are intellectual in their nature. The intellectual functions have a material substratum, molecular and cellular in character; the stronghold of the molecules and cells being located in the cortex or outer covering of the brain. The distinction drawn between voluntary and involuntary acts is more or less arbitrary if the nervous system and its workings only be considered. Thus voluntary actions, if often repeated, after a time become involuntary. Ordinary walking or walking without thinking affords an example. Ordinary walking is rhythmic in character, and resembles the rhythms so well seen in the viscera, which are in no way, or very little, under the influence of the will. Nerve action, wherever manifested, differs less in kind than in degree. Strictly speaking, a sharp line of demarcation cannot be drawn between what is a voluntary, an involuntary, and a mixed act, and it is not possible in the present state of science to determine what molecular and cell changes occur in the brain and nervous system when the several acts referred to are being performed. Neither can we distinguish with even approximate accuracy where the so-called voluntary acts begin in the lower animal forms.

Wherever feeling is manifested, nervous matter or its equivalent may be predicated, and where feeling exists a low form of cognition may usually be detected.

At one time reason was claimed exclusively for man. It is now admitted on all hands that a very large proportion of the lower animals, such as the monkey, elephant, dog, horse, bird, reptile, &c., not only reason, but in some cases reason acutely. The beasts of prey are obliged to resort to strategy in order to circumvent their victims. The spiders, ants, and bees perform feats of skill which cannot be correctly classed under vague terms such as automatic, reflex, instinctive, &c.

The Rev. G. Henslow[1] writes in this connection as follows: "The comparison is often made between man and animals, that man is said to have reason and that animals are devoid of it. A greater error can hardly be made. Any act done with some express purpose is of a reasonable nature, since there was 'a reason for doing it'; and the innumerable instances of 'animal intelligence' clearly prove that probably all but the lowest members of the various groups, vertebrates and invertebrates, are, *for them*, as much endowed respectively with reason as man himself.

"If, however, a reasonable act be constantly repeated it tends to become automatic; so that what we are *taught* to do, and at first do with effort, because we have to bring our minds or volition to bear upon it, can be done afterwards without any thought about it at all. Thus a person playing dance music has been known to have fallen asleep over the piano and yet continued to play correctly.

"This transference from the volitional to the automatic powers of the brain is of universal occurrence in everybody; and the act is still a reasonable act, although it may be done unconsciously, when it is called instinctive. In animals it becomes hereditary, and then such acts are recognised as instinct; so that each animal performs a stereotyped action with but little or no variations. It has been described as a marvellous instance of design that a wasp should know how to sting a caterpillar in three distinct spots in order to paralyse as many nerve centres without killing the creature.

"But there is nothing more extraordinary in this particular instance than in any other instinctive act, if we admit the discovery of the necessity by trial and experience, and then the perpetuation of the knowledge of it by hereditary memory.

"It may be asked, Why is it not so in man? The answer is that man has acquired other means for making his knowledge hereditary. He can record his observations, or by speech communicate them to a large number of his fellow-men. According to the universal law of compensation, he has thereby lost the 'hereditary memory'—that is, supposing him to have ever possessed it.

"Man differs from animals in having the power of *making an abstraction an object of thought.* He can reason about abstract things as well as concrete matters. Animals (as far as it is possible to judge of their capabilities by their behaviour) have no such power. Their reasonable acts are limited to concrete matters—that is, of sense only. . . . They can reason and act upon their reasonable intentions, and they do so every day; but it is always in connection with sense-objects.

"Again, it is said that speech separates man from animals. So it does, if by speech is meant definite words which can be represented by letters in writing. But animals 'speak' to one another by sounds, tones, and gestures. But so far as we can see and hear, it is always and all about concrete matters alone. Parrots can only mimic, they cannot 'speak.' A dog understands your tone of voice and expression of face and your gestures. He knows what you mean by words when repeated, so that he can learn to associate the sound of the word with some concrete thing; but dogs or other animals cannot hold conversations between themselves or with man. . . .

"Instinct—say that of migration of birds, which is now common to many races, whatever the species may be, consisting of hundreds of thousands of individuals—probably began in a small way, the distance of flight being increased by degrees, till the habit became a fixed and hereditary feature.

"In suggesting 'hereditary memory' as an interpretation for instinctive acts, one only expresses objective facts. . . .

"For all ordinary repetitions performed by every generation in succession we may, perhaps, with some degree of safety, assume this theoretical interpretation to be something near the truth; then the possibility of making acquired knowledge hereditary in animals, just as acquired bodily structures are hereditary, is a feature which appeals, on precisely the same grounds as the latter, to the power of an intelligent and all-powerful Organiser, or whatever term (ineffectual as all terms must be) we may choose to employ."

Every living thing in the universe, plant as well as animal, is cared for and provided with a guiding principle, which makes its workings within limits perfect and its life secure. Even in man, something like nine-tenths of his actions are of the involuntary type. Man in this respect is cared for in the sense that the plant and the lowest animal forms are cared for. He has no control over his circulation, respiration, secretions, excretions, assimilation, reproduction, &c. These processes, which are essential to his life and well being, are all carried on independently of his will, whether he is waking or sleeping.

The guiding principle in the higher animals and in man is the nervous system; but when this is absent, or cannot be demonstrated by even high powers of the microscope, it does not follow that a diffuse or unseen nervous system or its equivalent does not exist. We cannot possibly escape from the conclusion that everything that lives, lives according to rule and a predetermined plan, and not by accident or in a haphazard way.

[1] "The Argument of Adaptation or Natural Theology Reconsidered," by the Rev. George Henslow, M.A., F.L.S., F.G.S., &c. London, 1897.

An attempt has been made to establish an analogy between living forms with a nervous system but no brain, and those portions of our bodies which are regulated by nerve action but are not under the influence of the will. The attempt has led to much confusion. The peculiarity of the lower living forms with a nervous system, minus a brain, is that they move *voluntarily* and deliberately, whereas those parts of our bodies which are not under the influence of the will move *involuntarily*. It is, therefore, wholly inaccurate to speak of the movements of the former as automatic, reflex, instinctive, &c. Indeed it becomes a question whether these terms should not be eliminated from physiology. They have no meaning apart from theory, and are mere cloaks for ignorance. Living things are masters of the situation, and possess in themselves the power of moving, selecting, digesting, assimilating, growing, procreating, &c. They do not require to be acted upon from without by irritants, or jogged into activity.

It is convenient in man and in the higher animals to speak of voluntary, mixed, and involuntary movements —the latter including the so-called reflex movements; but it cannot be accurate to describe the movements of an animal with a nervous system and no brain as involuntary or reflex when that animal can, and does, move deliberately and in given directions to accomplish a given object.

The sensitive nerves, as explained, extend between the integument and ganglia, and convey sensory impressions from without inwards. By means of these simple arrangements the several parts of the animal are connected with each other, and the animal as a whole is made aware of matter outside of itself and its surroundings. It can move its several parts voluntarily, and it can advance towards or away from extraneous matter at will. It can seize appetising morsels of food, and it can withdraw itself from disagreeable or irritating substances. It performs not only the involuntary movements embraced in the vegetative functions of all animals, but also in a limited sense the voluntary movements necessary for seizing what it likes and escaping from what it dislikes.

Voluntary movements imply volition and will, in however rudimentary a form, and volition in such cases is based upon cognition or a knowledge of things extraneous to itself. That the medusa and star-fish feel, goes without saying. All this is done in the absence of a brain in the ordinary sense, unless perchance each ganglion be considered a rudimentary brain—a view not at all improbable, seeing that similar ganglia and nerve fibres are found in very large numbers in the brains of all the higher animals, man included. They also occur in great quantity in the spinal cords of the higher animals, the brain in them, as has been pointed out, being a mere expansion of the elements composing the spinal cord, as the skull is a modification and amplification of the vertebræ forming the vertebral column. If this view of the nervous system in the lower and lowest animal forms be adopted it will afford an explanation of their purpose-like movements and power of selection, which are otherwise inexplicable.

It will also account for the extraordinary powers exerted by certain of the tissues, especially the glands, in the highest animals, when they act as if almost endowed with intelligence.

The brainless view, if I may so call it, of the nervous system gives continuity of structure and function, and admits of endless modification in the animal series from the lowest to the highest.

In the centipede, as has been pointed out, the nervous system consists of a double chain of ganglia with connecting fibres extending in the direction of the length of the animal, the ganglia being provided with sensory and motor nerves for each limb, which take a transverse direction or run across it (Plate cxxxi., Fig. 3, A, p. 749). The two uppermost ganglia, which are more developed than the others, coalesce to form a rudimentary brain. In this simple segmented animal the spinal cord and brain of the higher vertebrates, man included, are clearly indicated. The coalescence of the two anterior or cephalic ganglia produces a symmetrical brain, which sends out nerve processes akin to sense organs. But (and this is the point) the brain and the ganglia from which the brain is developed are virtually identical. In other words, there is in the centipede but one step, and a short one, between any two ganglia and the brain formed by their coalition. In the lower and lowest animals the ganglia by implication take the place of the brain in the higher and highest.

The brain, even in man, consists of a double row of ganglia with innumerable nerve cells analogous to, if not identical with, similar ganglia and nerve cells found in the centipede and comparatively rudimentary animals.

In the spinal cord of the vertebrata, man included, large numbers of ganglia and nerve cells are found, and these unquestionably foreshadow and typify similar structures occurring in the brain itself. It is in man and the higher vertebrates that the reasoning powers are most developed and the voluntary movements seen to greatest advantage. Over these voluntary movements the brain as a whole presides.

The involuntary movements are for the most part under the influence of the spinal cord and the sympathetic system of nerves, both of which display quite a wealth of nerve cells and ganglia.

The spinal cord and sympathetic system of nerves, with their numerous ganglia and nerve cells, regulate the so-called involuntary movements, but the latter movements, seeing they are co-ordinated and purpose-like—movements, in fact, to a given end—are in no sense haphazard or accidental. They are in reality as necessary to the

well-being of the animal as the voluntary movements. The movements of the heart, respiration, secretion, excretion, assimilation, &c., are all classed as involuntary, but life actually depends upon them.

There is no doubt a considerable gap between a diffuse, invisible nervous system such as may exist in the plant and the lowest animal forms, and the simplest visible nervous system; but given a nervous system such as we behold in the medusa, the star-fish, and the centipede, the advance to a spinal cord, a sympathetic system, and a brain such as we behold in the higher vertebrates and in man becomes rapid, and the more we examine into the minute structure of the nervous system as a whole the more we are forced to conclude that there are fundamental points of resemblance between the lowest and highest forms of nerve matter.

Some fifty years ago Mr. Lockhart Clarke devised a process for showing the ganglia, nerve cells, and nerve fibres of the spinal cord. He hardened the cord in spirit, cut it into marvellously thin, transverse, and longitudinal sections with a fine razor, and these he stained with carmine, made transparent with turpentine, and mounted in canada balsam. The nerve cells and ganglia so prepared took a deeper dye than the blood-vessels, lymphatics, and molecular portions of the cord, and when the thin sections containing them were examined by the aid of the microscope they stood out in bold relief. These ganglia and nerve cells displayed nerve filaments proceeding to and from them, showing clearly that the nerve cells and ganglia formed centres in the nervous system.

Mr. Clarke by his new method demonstrated similar nerve cells and ganglia and nerve filaments in the brain itself. Here was a notable advance, and one in which I took a keen interest, having been introduced to Mr. Clarke at Edinburgh University when I was a student and class assistant to Dr. J. Hughes Bennett, the Professor of Physiology. I, moreover, had the good fortune to procure at a subsequent date a very extensive and perfect collection of microscopic brain and spinal cord sections prepared after Mr. Clarke's methods by Mr. A. B. Stirling, the Curator of the Edinburgh University Anatomical Museum.[1]

Quite recently, indeed within the last few years, the minute anatomy of the brain has received an extraordinary impulse from researches in a similar direction on the part of Bevan Lewis, an Englishman; Golgi, an Italian; Ramon y Cajal, a Spaniard; and Nissl, a German. These four investigators set themselves the difficult task of devising methods and stains which would differentiate and reveal under high powers of the microscope all the different textures entering into the composition of the brain.

The methods and the results obtained by the above four investigators have been graphically described by my friend and fellow-graduate, Dr. Thomas S. Clouston, Lecturer on Insanity to the Royal College of Surgeons, Edinburgh, as under :—

"The brain happens to be by far the most difficult part of the body to investigate as to its structure. The microscope had to be brought to great perfection before its (the brain) inconceivably minute and extraordinarily complicated mechanism could possibly be seen. Chemical methods had to be devised for hardening its delicate jelly-like consistence, instruments had to be invented for shaving off slices of it when thus hardened only one three-thousandth of an inch thick, devices had to be thought out for clearing up these thin slices so that they could be clearly seen through the microscope. Then different stains for the different constituents of the brain, whereby each could be dyed and so distinguished from one another, had to be discovered. For in each of these film-like slices are contained innumerable blood-vessels, lymphatics, packing and supporting 'nerve glue,' cells and fibres by the million that act as guy ropes, before ever one comes to the essential nerve elements themselves. Every one of these may be 'selected' by special staining materials. Staining often means elaborate chemical and mechanical processes. Long ago investigators made out nerve fibres in the brain and cord, then 'nerve cells' were found to exist in myriads, but how the cells and fibres stood related to each other has only now been clearly made out. . . .

"Up to Bevan Lewis's time the method of hardening by chemical agency small portions of brain, cutting them into thin slices, and then dyeing them with staining material, had made much progress, and had yielded wonderful results. But there was always the possible fallacy that perhaps the real brain mechanism was altered seriously by the chemicals used to harden it. He devised the method of freezing small bits of brain to make them solid so that they could be cut, and then staining the sections with a very simple material—aniline blue-black. In this way the

[1] Mr. Stirling was a highly gifted, ingenious man, who could turn his hand to anything. He was the original inventor of the microtome or graduated microscopic section cutter, and excelled all others of his day in mechanical microscopic methods. By means of his microtome he made the thinnest microscopic sections on record. He was a famous injector and stainer of specimens, and was the first to prepare microscopic specimens on a large scale for students. Some of his injected and stained specimens have never been surpassed. I was fortunate enough to secure a large miscellaneous collection of his choicest products, which I greatly prize, alike for their great scientific value and as a reminiscence of one whom I very much esteemed, and to whom I was greatly indebted for many valuable lessons in injecting and preparation-making.

Mr. Stirling's original microtome consisted of a very carefully planned horizontal metal table or stage, with a circular aperture in its centre. Round the aperture, and securely attached to the under surface of the table, was a vertical tube depending at right angles. This tube contained in its interior a very finely graduated female screw. The corresponding male screw was entered from beneath, and was provided with a flat head above and a thumb screw beneath. It carried the specimens to be cut on the top, these being imbedded in fat, wax, paraffin, and other supporting media. The sections were made with the aid of a very sharp, specially prepared, flat razor. By carefully adjusting the male screw, sections of any degree of fineness could be easily and accurately produced. Various modifications of the microtome have been manufactured since Stirling's day, but to him undoubtedly belongs the original idea.

brain mechanism was not altered. Its constituents were seen, in fact, as they existed in nature. The brain was thus clearly seen to consist of innumerable cells of four or five different kinds, each cell with a distinct nucleus, each having a mass of fine nerve protoplasm, which sent out processes or fibres in all directions. These cells were manifestly the active agents of the brain to do its work of motion, sensation, nutrition, and mentalisation. Lying round them, to nourish them, to drain away used up material, and to support them, Lewis's method most distinctly showed a network of small blood-vessels, lymphatic drainage spaces, packing cells, and guy rope fibres. To look at a section of the outer crust or 'cortex' of the brain prepared by this method, with a good microscope, was a very beautiful sight. It is something like looking up at a tree just coming into leaf, with a great number of crows' nests sticking all through the smaller twigs, only you had to imagine you saw through the nests so that the eggs inside were visible. By this method, too, more of the differences between a healthy brain and a softened brain or an insane brain could be seen than before. This was an enormous gain to science and humanity. The weak points of the method were that the connections of the cells with the outgoing fibres that conducted their influences to the muscles were not always clearly made out; nor was it possible to trace those fibres far; nor could the differences between those outgoing fibres and the incoming fibres that bring impressions from the outside world through the eyes and ears and skin, &c., to the brain be made out. In fact, certain important points were cleared up, but the whole mechanism was not fully made out.

"Then came Golgi's epoch-making device and discovery. He invented a method of steeping brain cells and fibres in a solution of nitrate of silver, and of then precipitating it on them, making each of them black, so that it stood out in the field of the microscope like a tree against snow on a winter day. By this method a perfectly new light was thrown on brain cells and brain mechanism. Each cell was shown to be the centre of an elaborate system of fibres proceeding from all sides of it, these fibres or 'dendrites' splitting up and branching out in all directions, running long distances through the brain, and being covered by small bulbous bodies like the ultimate rootlets of a plant, these being called 'gemmules.' One fibre of each cell was different from the others, and proceeded from the cell out of the brain down into the spinal cord, and no doubt in many cases into the nerves of the limbs and muscles, this being called the 'nerve axis.' The whole cell apparatus taken together—cell body, nucleus, dendrites, gemmules, and nerve axis—was re-christened 'the neuron,' or central active nerve element. No direct fibre connection seemed to exist between one neuron and another, so that the nerve energy would seem to pass from one to another by contact, not by continuous tissue. This was a new and startling fact in neurology. But it has already been questioned, for two investigators say they have demonstrated fine fibres of direct connection between one neuron and another, which we think very likely to be the case. Ramon y Cajal, perfecting Golgi's methods, has extended his observations, and made them more scientific and certain, using them as a broad basis of research in the whole brain mechanism. The general result is that we have the brain demonstrated to contain three thousand million neurons, each with one nerve axis, at least forty dendrites, and each dendrite with more than a thousand gemmules; so that we have the amazing result of every man and woman among us carrying in his brain this inconceivable number of active energising structures to carry out his feelings, his movements, and his thinking for him: and all these are combined in infinite connections of small groups and large groupings, so as to regulate every function we perform, to report every sensation we feel, and to recombine every perception and reminiscence in the processes of will, thought, and imagination. All that every man has learned in walking, playing games, singing, and working, all that he has seen and heard and read and thought and imagined, is, by means of the vital activity of these neurons, fixed and stored up and made a part of his bodily and mental life and experience. Truly, mind is great and incomprehensible, but so is the brain mechanism through which it manifests itself.

"Science is never satisfied till perfect knowledge is attained, and Golgi and Ramon y Cajal had left many points still unsolved about these wondrous neurons of the brain; so Nissl in Germany devised another mode of staining and treating the nerve cell which demonstrated its internal structure better than ever before. This method shows each cell to consist of an immense number of small, regularly disposed bodies, 'chromatic granules,' or 'chromatophyle' bodies, so called from their affinity for taking on stains, by which they come out vividly under the microscope. In addition to this, minute fibres of inconceivable fineness can be seen by another method running all through the body of each neuron among the chromatic granules, into and from its dendrites and nerve axis, making the whole look somewhat like the section of a ball of worsted that had been steeped in glue. Nissl, by his method, distinguishes eight different kinds of nerve cells. Most valuable results to science have been obtained through examination by the Nissl method of the brains of those who have died of nervous diseases. A process of what has been called 'chromatolysis,' or a disturbance of the regular arrangement of these chromatic granules, is found to have taken place in certain nervous diseases, in insanity, in idiocy, and in extreme old age. A section of brain treated by the Nissl method is a most beautiful object looked at through the microscope, even to a non-

expert observer. For an absolutely thorough examination of a brain supposed to have suffered from disease, so as to be able to discover every possible change that may have taken place in it, we now have to take many small portions of it, and subject each to the Lewis, the Golgi, and the Nissl methods of preparation and examination; and each portion must then be cut into fine sections, each section being carefully gone all over by the microscope. As can be readily understood, all this implies such fine handling and careful use of the chemical reagents, that it needs an expert to make the preparations and then to tell the meaning of what is seen. It now takes over a month for such an expert to examine a single brain. We have no doubt that shortly a special mode of preparation will be needed to show each structure in the brain—one method for the blood-vessels, one for the nerve glue, one for the protoplasm of the neurons, one for their nuclei, and one for the dendrites.

"Thus are specialisms in science ever more developed, because the methods of accurate scientific research are becoming ever more delicate and elaborate."

The extraordinarily complicated structure of the human brain may well excite feelings of astonishment, but these quickly disappear when the marvellous powers of the mind are taken into account. It is only by the patient investigation of structure that function can be satisfactorily determined, and the foregoing elaborate researches into the minute anatomy of the brain in health and disease have done more to elucidate the mysterious workings of the mind than all the speculations of philosophers from the beginning of the world till the present.

The fine-spun theories of the immaterialists as to the nature of mind are being slowly but surely discredited, and it is no longer considered possible to evolve from the inner consciousness a working hypothesis of the intellectual functions which will bear the light of modern science.

That mind has a physical basis and is material in its nature, and that the brain is the seat of the intellectual functions, seems proved not only by the microscopic structure of the brain in health and disease, but also by the following facts :—

(*a*) Consciousness and all the attributes peculiar to mind instantly disappear if the head be struck violently and the molecular balance of the brain be disturbed.

(*b*) The same thing happens if the brain be compressed by a depressed portion of the skull, the result of accident or the extravasation of blood on the surface or in the substance of the brain. Similar results follow the gradual softening of the brain.

(*c*) The activity of the brain is affected by the quantity of blood in it at any given time. Thus after a full meal, when the stomach largely draws the blood out of the brain for the purposes of digestion, the individual is drowsy and the mind sluggish. Digestion impairs the nourishment and activity of the brain for the time being.

(*c′*) The brain is inoperative when largely depleted of blood as in sleep, dreams fantastic and incoherent being its only product.

(*d*) If the brain be sliced away in a direction from above downwards, the intellectual functions disappear as the base of the brain is approached.

(*e*) Intellectual power keeps pace with brain development, the value of the brain being determined by its size and quality.

(*f*) The brain of the child is large, but very fluid and poor in quality, hence its inefficiency.

(*g*) The brain of an uncivilised savage is small as compared with a European brain—the wild man is intellectually much inferior to the educated man.

(*h*) The size of the brain as contrasted with that of the body determines, within limits, the intellectual power of the individual, whether man or animal.

(*i*) All animals remarkable for strategy and reasoning powers have large brains. The monkey and elephant, the most sagacious of animals, may be cited in this connection.

(*j*) The birds and beasts of prey have larger brains than the animals on which they feed.

(*k*) Wild animals have larger brains than domestic animals of the same species. The former require to find their food : the latter have it provided for them.

(*l*) The brain becomes larger as we ascend from the lower to the higher vertebrates until man is reached—a circumstance which makes it very difficult to determine where reasoning begins. That brain and brain function culminate in man is incontrovertible, but that a comparatively large number of animals reason cannot in the present state of science seriously be doubted.

(*m*) The training of animals and the education of man proceed on the assumption that the brain as the organ of the mind is capable of development and improvement from the physical side.

(*n*) Improved psychical qualities are secured by education, and some are of opinion that they are transmitted.

It may be added that the profession of medicine from the earliest times has strongly inclined to the materialistic view of mind, and has treated cases of insanity as cases of bodily ailment. It has never prescribed

metaphysics as likely to benefit such patients ; on the contrary, it has taken a common-sense view of the malady, and has ordered such remedies as would improve the general health, on the principle " *mens sana in corpore sano*." The immortal Shakespeare touches the kernel of the matter when he asks, " Canst thou not minister to a mind diseased ? " A diseased mind necessarily implies a diseased brain. It would be ridiculous, and a contradiction in language, to speak of an *immaterial* disease.

§ 231. The Relations existing between Brain and Muscle.

These are of the most intimate and interesting description. It will not be too much to say that without muscle the brain in the higher animals and in man could not assert itself—could not be even properly developed.

This follows because the sense organs of feeling, tasting, smelling, hearing, and seeing, to which may be added the sense of weight, are dependent upon muscles for the due performance of their very varied and most delicate functions. The skin, or outer covering of the body, which is in contact with the outer world at all points, is the parent of the sense organs. These are, in every instance, mere developments or differentiations of the integument. Even the eye and ear in many respects resemble the various touch corpuscles, especially the Pacinian bodies of the skin. The sense organs as auxiliaries of the brain have been already described.

The brain obtains all its information regarding the outer world from the sense organs, and these elaborate and highly differentiated structures are moved by muscles to a degree of nicety which baffles description.

To take examples, the muscles of the body, and of the hand especially, enable us to touch extraneous substances of all kinds ; the muscles of the tongue, cheek, palate, and fauces are brought into requisition in tasting ; the muscles of the nares or nostrils in the sniffing required for smelling ; the muscles of the ear in hearing, and those of the eye in seeing.

The muscular operations of the sense organs in hearing and seeing are of the most complicated and delicate character. The membrana tympani or drum of the ear is stretched by muscular action to such an extraordinary degree of nicety that it receives and transmits to the inner ear every conceivable form of sound wave and vibration generated by sounding bodies near and remote.[1] All the gradations of sound, musical notes, and harmonies are indirectly the product of muscular action. In like manner the muscles of the eye give to that wonderful organ its characteristic movements and mysterious, far-reaching power.

The mysteries of expression—subtle, sudden, and often electrical in their effects, as far as the eye is concerned —are due to muscular action. The dilatation and contraction of the pupil, the rolling of the eyeballs—all the movements which confer on the eyes their marvellous aptitude for expressing love, hate, disdain, anger, despair, fear, sorrow, &c.—are muscular in their nature. Nay more, by the aid of the muscles the eyes can be made to accommodate themselves to distance, whereby they can see things clearly at a few inches or objects so remote as the sun, moon, and stars. They can be adjusted to behold and by the aid of the telescope to study the marvellously resplendent heavenly bodies—the world of the immeasurably great. They can also be adapted to see, and, by the aid of the microscope, to ponder the world of the infinitely little. Wonder upon wonder flashes into the brain through the eyes, but muscles, especially those of the iris, are required to open, so to speak, the windows of the eyes.

Without the sense organs and the muscles which move them, the brain, as indicated, could not be developed and educated.

An individual deaf and blind from birth is necessarily a very imperfect being, and his brain, comparatively speaking, is of a low order. Such an one is necessarily dumb. He is denied the power of speech, and words are virtually wasted upon him. It is impossible to convey to him an idea of the music of the spheres, or the concatenations of sweet sounds which go to form concerted harmony ; neither can he be made fully to realise the nature of the human voice, the singing of birds, the lowing of the kine, and the innumerable sounds emitted by domestic and wild animals, which conduce so much to our enjoyment and happiness.[2]

The voice—that touchstone of humanity in all ages—with its wonderful power of modulation, exceeding in subtlety all the instruments which have been or can be fashioned by the ingenuity of man, is also the direct product of muscular action.

The vocal chords, as well as the chest, which supplies the bellows for setting them in motion, are dependent on muscles.

The vocal chords, like the drum of the ear, can be strung up by muscular action to an extraordinary degree

[1] The range of the human ear, it should be explained, is limited. The ear cannot hear both the highest and lowest notes. The power of hearing is also varied ; some people hearing low notes well, and the higher notes imperfectly or not at all. The rule is, that those who hear low notes distinctly hear high notes indistinctly, and the converse.

[2] Of late years the deaf have been taught to interpret the movements of the lips of persons speaking, and with a very considerable degree of success. Lip reading is a very important auxiliary to the finger reading formerly employed.

of perfection. There is, however, this difference; whereas the drum of the ear is strung up and attuned to *receive* vibrations, sound waves, and musical notes, the vocal chords are strung up to *produce* vibrations, sound waves, ordinary speech, and song. The drum of the ear may be regarded as the active instrument for sound reception, the vocal chords the active instrument for sound production. The one is the complement of the other, and both must be highly developed before perfection in speech or song can be attained.

The power of speech and song are among God's choicest gifts to man. The orator can stir up and sway humanity in its thousands, and the prima donna can electrify and subdue to melting mood vast audiences both of educated and uneducated people.

Music is in some senses a universal language, and the power of the orator is felt even when his language is strange and cannot be interpreted. His power is largely muscular, due to intonation, to the expression of the eye and face, to gesticulations of various kinds, and to the movements of the whole body, as it sways to and fro under the influence of passion as a tree trembles and bends under the influence of a storm.

The impulses of head, heart, and soul find fitting expression in the muscular movements of the frame as a whole. An orator without gesture would be a signal failure. It is the ever-varying expression of voice, eye, face, and body which rivets and commands attention. The orator deals with impulses in himself and in others, and the impulses in both cases are rhythmic in character. The same may be said of music. The cadences of music as they rise and fall irresistibly affect man and even the lower animals. The beat or rhythm of music causes the whole frame to vibrate. It produces every possible kind of emotion. The untutored strains of the Æolian harp move many to tears. In this case it is the breathing air which supplies the delicate impulses which stir our inmost being. The echo produces similar impulses as it floats about and becomes more and more faint and dies in the distance. In this instance we realise, or seem to realise, that there is a mysterious connection between this world and a world beyond.

Music even more than oratory sways humanity. This is due to its more strictly rhythmic character, and to the fact that it is always marked off by distinct time intervals or beats. The music may be fast or slow, or it may be lively or sad, but the time element always crops up.

It is the recurrence of musical notes at stated intervals, and the emphasis which is placed on them, which so visibly affects us. We speak of the crescendo and the diminuendo, or the verve and swing of a piece. Of the smooth-flowing and well-accentuated rhythmic melodies the waltz is perhaps the best example, and certainly no better instance can be adduced as proving the direct connection which obtains between mind and muscle.

The rhythms originating in the brain of the composer are taken up and repeated with the greatest enthusiasm by the votaries of the ballroom. Every form of dancing is more or less rhythmic in character. Time intervals are necessary to all music. An orchestra without its drums would be more or less ineffective. The drums can scarcely be called musical, but they beat or mark time, and are invaluable auxiliaries. They arouse the rhythms which exist in the audience in a way nothing else could. The drums are especially effective in martial music.

The cadences of the voice, and the movements of the eyes, which in a sense dance attendance on the voice, are rhythmic and muscular in their nature. The eyeballs are kept moist by the rhythmic muscular movements of the eyelids.

The eyes literally light up the face—they are to a face what water is to a landscape.

The voice, like the eye, is capable of infinite expression, and all the emotions, from the tenderest love to the fiercest hate, can be expressed by it.

Truly the power of muscle in its infinite combinations and effects becomes more and more startling in proportion as that power is studied.

What a moving panorama of muscular action is the human face! The muscles of expression can make even a plain face beautiful, and the most finely chiselled countenance can by them be transformed into that of a fiend. The muscles of expression, though numerous, are small in volume. They are, however, *par excellence* brain muscles, being supplied with comparatively very large nerves, and being only separated from the sensorium by a few inches. Their action is consequently very exact, and in a sense instantaneous.

It is next to impossible to catch and fix the ever-varying expression of the countenance even by the aid of instantaneous photography, and some of the finest faces are practically lost to posterity from the inability of the artist to depict their evanescent beauties. As the landscape changes under the influence of light and shade, so the countenance alters under gay or sad feelings.

The prevailing tenor of the mind is stamped upon the face as surely as the prevailing direction of the wind is stamped upon a tree on a hill top.

The face is eminently plastic, especially in youth, and everything that passes through the mind finds expression in the features. The face is gay, pensive, and sad by turns. It is the mirror of the mind, as the eyes are the

mirror of the soul. In the face and eyes the most secret thoughts can be read; only the practised villain can successfully dissemble. The very mobile face with the still more mobile eyes responds to every form of emotion. The storm of the passions is as visible on the face as a hurricane of wind on the surface of the ocean.

All these wonderful results are due to muscular action.

Expression is not necessarily confined to the face. There is the expression of form. This applies to every part of the body. We speak of the expression of a hand, the expression of a foot, the expression of a limb. How daintily the hand and foot can be made to move, and with what grace, dignity, and stateliness the head and trunk can be carried!

Walking, swimming, and flying afford examples of expression. These movements are voluntary in their nature at the outset, and show in the most conclusive manner the very intimate connection which exists between the brain and the muscles.

Walking, swimming, and flying have all to be learned. The muscles engaged in producing the several movements have all to be trained. The brain during the training process is very actively engaged, and it is only by frequent repetitions at stated intervals that the art of walking, swimming, or flying is acquired.

The efforts of brain and muscle put forth at intervals in the efforts of walking, swimming, and flying are essentially rhythmic in their nature, and the walking, swimming, and flying movements, when once acquired, may truly be described as rhythmic. The acquired movements are also more or less involuntary. Every one, however, is aware of the great difficulty experienced by the child in learning to walk. The fish experiences a like difficulty in swimming, as proved by the comparatively ineffectual and feeble action of the tail in a young or developing fish. Similar remarks apply to the insect, bird, and bat in flying. An insect flutters its wings ineffectually long before it flies, and birds and bats, even in the nests, make their wings quiver in anticipation of their aërial destiny. Birds and bats, in addition to the fluttering in the nest, are taught by their parents how to fly. The training is in some cases prolonged, and affords an interesting study. Only the shortest flights are at first essayed, and the timidity of the pupil and the anxiety of the mother are equally apparent. The efforts made by young seals in their first attempts at swimming (and the same may be said of the young of the sea-lion and walrus) sufficiently attest the difficulty experienced in acquiring the art. There are, however, some animals which seem to be able to swim when first thrown into the water—as, for example, the cat and the dog. In these cases the movements of swimming are nearly identical with those of walking, and are largely automatic.

Walking, swimming, and flying, as stated, are all voluntary movements to begin with—they involve the joint action of the brain and muscles. By the force of habit and constant repetition they become more or less involuntary. It would, however, be a great mistake to say that walking, swimming, and flying are simply automatic or mechanical at any period of existence.

Some authors, oblivious to, or ignorant of, the voluntary efforts made by all animals in their efforts to walk, swim, or fly, have gone the length of asserting that flying, which is the most difficult and complicated of all the forms of locomotion, is a mere mechanical act. The statement is preposterous. One has only to examine the brain, the nervous system, and the muscular arrangements of a bird to be convinced that every part of the wing—even the primary, secondary, and tertiary feathers—during every part of the down and up strokes is completely under the will of the animal. In proof of what is here stated it may be mentioned that if the cerebellum or little brain of the bird, which co-ordinates the flight movements, be removed, the animal flutters its wings violently but to no purpose. It cannot fly, however serious and vigorous its attempts. The movements of the wings are sprawling, blundering, and ineffective; sufficient and more than sufficient force is exerted, but the force is not properly directed and timed, and failure inevitably follows. Similar results follow division of the motor nerves of the wing.

The movements of the wings in flight are never haphazard. On the contrary, every part of the up and down strokes is visibly under control. When the wing is elevated it is flexed or folded, and the primary and secondary feathers—especially the former—are thrown out of gearing and opened up, so as to avoid the superincumbent air and reduce friction. When the wing is depressed it is extended or expanded, and its primary and secondary feathers closed to seize the nether air and increase resistance and friction. Not only so, but the angles made by the under surface of the wing with the horizon, and the varying speed with which the wing is propelled at every part of the up and down strokes, are all duly regulated. Further, the wing during the up stroke draws after it an upward current of air which the descending wing meets and, so to speak, seizes by a sudden flick. The flick occurs at the beginning of the down stroke—the force of the down stroke being added to or multiplied to that of the up stroke, with the result that the wing obtains a degree of support or leverage similar to what would be obtained if it struck a solid.

I desire to point out and emphasise this fact, which has hitherto been overlooked.

If the flick referred to be omitted, ordinary flight becomes impossible. Ordinary flight is not to be confounded with sailing flight, which is a species of ordinary flight, and will be described separately.

While adults forget the extreme trouble experienced by them in learning to walk, they never forget the efforts put forth in learning to swim, skate, ride, cycle, row, &c.

These artificial movements are acquired later in life, when memory is more fully developed. They ultimately become as easy as walking. Walking and all the movements referred to are very complex, difficult, associated movements, where the brain as well as the muscles has to be taught its lesson, and where brain and muscle must work harmoniously together. At first it seems impossible that the limbs could ever be trained to perform them; yet by perseverance and repetition at intervals all the difficulties gradually disappear.

One naturally asks, Why should artificial movements be so difficult to learn? The answer is not far to seek. Artificial movements must at the outset be voluntary movements, and, as indicated, not one muscle, but many muscles, must be trained by the mind to act together at particular intervals to obtain definite results.

There must be unison or oneness, so to speak, as regards the volitions and the muscular acts. The brain must not be acting in one direction and the muscles in another. There must be co-ordination. Mind, muscle, and the nervous system as a whole are involved, and much time, effort, and repetition are required to bring the three into line, so that they may work smoothly and consentaneously. Any hitch, structural or functional, and the particular movement becomes impossible. Paralysis, for example, puts an end to all voluntary and all acquired movements.

Voluntary and involuntary muscular movements are very largely due to muscular training and repetition.

The muscles, whether voluntary or involuntary, must move in given directions at given times and to given ends. They must not oppose each other. Their action must be conjoint and simultaneous. The number of muscles employed varies according to circumstances. They may be few or many. A muscle seldom or never acts by itself, and there are cases when nearly every muscle in the body is brought into play. This happens in violent respiratory movements.

The muscles, like the mind, can be developed and educated. The muscles of the athlete afford an example of such training. All the arts are dependent on trained muscles. The delicate hand of the artist, the deft fingers of the watchmaker, the brawny arm of the blacksmith, the powerful arms, shoulders, and chest of the oarsman and pugilist, the sinewy, strong limbs and feet of the pedestrian and *danseuse*, all proclaim the doctrine of muscle evolution and education.

Those who excel in the arts and in physical sports are, as a rule, provided with good brains.

Mind and muscle, it will be seen, are mysteriously linked together. The relations of mind to muscle are of the most intimate, mysterious, and far-reaching character.

Dr. Thomas Clouston, to whom reference has already been made, thus speaks of the connection :—

"The proposition that muscle is the essential co-relative of mind, and its necessary accompaniment, at least in this world, would not at first be generally accepted. The statements, made as scientific truths, that mind could not express itself in any way except through muscle, and could not have been developed or even existed in any but the most rudimentary form in man or any living being apart from muscle, would certainly not find an immediate assent from most intelligent persons. Yet these statements are mere physiological and psychological truisms, which any ordinary educated man may very soon convince himself of by a little physiological reading, or even by a consideration of facts within the reach of all.

"Take first the faculty of speech. It is essentially a muscular act, originated as an objective fact by various sets of muscles which compress or expand the chest to produce the air currents and pressures in the larynx and mouth and nose, whose delicate and complicated sets of muscles then regulate the sounds and tones produced, and so create that human voice and speech through which ideas, emotions, and volitions are expressed, and through which human intercourse and all the higher social instincts find vent.

"But some one will say, Is not this an illustration that muscle is the mere servant and instrument of mind, the master? To answer this we need to go further back, and see the influence of speech on the origination and development of mind. All psychologists now agree with Max Müller that without speech mind could never have got beyond the simplest stage of animal feelings and concrete ideas. Man could not have been man as we know him without speech. Mind would have still stood at its lowest level, except for that series of muscular acts which constitute human speech. As it now exists in man, if we trace its origin in the brain through the nerves of the vocal organs, it has two great 'centres' mixed up with the mind centres, one sensory, for taking and laying up the words and ideas heard through the ear, and the other motor, in which the complicated sounds and tones of articulation are 'made up,' as it were, before ever they become audible speech at all. The destruction of either of those speech centres in the brain by disease not only destroys the power of speech, but so impairs the mind that commonly reason and will are markedly reduced or perverted. Thus mind and muscle are in speech inseparable

and virtually dependent. Mind has reached the stage of abstract ideas solely through the help of the muscles of speech, and those muscles have thus been enabled to give concrete form to thought and emotion of the highest and most subtle kind, while the mental energies which they have helped to develop have in their turn helped to perfect the speech muscles.

"Then observe how muscle helps in the education and development which the mind receives from the senses during childhood. Every waking minute from birth does the child's brain receive an inrush of impressions from the senses—impressions of form and colour, motion and distance, from the eyes and touch, of sound from the ear, of smell and taste from the nose and mouth, every one of these leaving some permanent impression on the brain and mind, and every one adding more or less to the stock of knowledge and power of comparison and reasoning. Long before speech comes, the basis of mind is thus being laid. If the sense of hearing be absent, speech never comes; if it be imperfect, speech is apt to be imperfect. If the sight be absent or deficient, a whole mass of educative impressions is lost, and the mind to that extent remains contracted and imperfect. If hearing and sight are both deficient or very imperfect, a condition of arrested mental development closely resembling idiocy results, except where touch is by a special training made in some degree to supply their place. But the eye or ear cannot perform their functions properly or give accurate impressions of the outside world to the brain except through their muscular arrangements. It is through their muscles that the ear can distinguish the quality and direction of sounds, and the eye can distinguish and appreciate the size and distance of objects, and can exclude or receive the amount of light that is needed for perfect pictures on the retina. Without muscular arrangements these organs, instead of being the most perfect and wondrous bits of self-adaptive machinery in nature, would be but poor receptive organs, that would send up to the mind clouded and misleading impressions of the outside world, and so the whole mental development would be twisted and imperfect. The sense of touch or common sensibility would be of little use if the touch organs could not be moved over the surfaces to be felt. Then the muscular sense which tells of weight and direction resides in muscle itself. In short, but for muscle the mind of a child would remain undeveloped or be educated on wrong lines in acquiring its essential knowledge of the outside world through the senses, and so an imperfect power of reasoning would result.

"The mind can only express itself to the outside world through muscle. We have seen how this holds good of speech. It is the same with the 'expression' of the face and eyes and the mental-muscular acts of laughter and tears, of sighing and groaning, of attitudes and gestures. Every sign by which we judge that a man is happy or miserable, is weary or alert, is suspicious or trustful, is angry or pleased, is telling a lie or the truth, is a muscular sign. Most of the hundreds of the muscles in the body can be made to take part in expressing some mental or emotional state. But in the face and eye we have a large number of small muscles capable of the most delicate grades of action and the most complex co-ordination among themselves, all of them existing solely for the purpose of expressing mental states. Those may be called *par excellence* 'the mind muscles.' They have an enormous nerve supply direct from the brain. Placed on scales, they (the muscles) would altogether scarcely weigh an ounce. Yet their nerves are together far larger in size than the nerves going to the large muscles of the thigh, which muscles weigh several pounds. This means that they can act with infinite quickness and delicacy, and with infinite grades of complexity of co-ordination with each other in executing the mind's behests.

"The late Professor Laycock, of Edinburgh, was famous for his physiognomical diagnosis of disease. In treatises on mental diseases, this subject is, of course, necessarily and constantly referred to. No natural beauty of face or eye or grace of movement long survive a severe attack of acute insanity. When mental recovery is taking place, one of the first signs is a return to the natural expression of face. When in regard to a patient or a friend we say, 'He is not the same man,' we usually mean that his mind muscles of face and eye have so changed in their working that a changed state of mind and emotion exists.

"Muscle is as necessary for the writer as for the speaker. In the brain of the educated man of civilisation there has been developed a 'writing centre' near the speech centres which, like them, is mixed up with the mental areas. If this gets damaged the greatest writer is as helpless as the babe to influence his fellows by written language. If he thus becomes 'agraphic,' he can neither write his thoughts nor even understand his own written or printed page any more than the naked savage.

"Every set of muscles and the functions they are designed to perform are 'represented' in the brain, just as ideas and memories and sense impressions are represented there in groups of its million cells and their connections. Hence we can in dreams or reveries have vivid impressions of muscular acts with no real muscle movements at all. We may have muscular hallucinations, in fact, just as we can have mental hallucinations. We have a muscular memory, too, just as we have a mental memory. The use and co-ordination of groups of muscles for certain purposes become easier the more frequently they are practised, just as intellectual acts become easier by repetition. In both cases the new combinations of cell action and paths of conduction in the brain become

'organised' and fixed, like new wires and stations in the development of a telegraph system when new villages are taken into the existing circuit.

"When we try to discover the ultimate apparatus in the brain through which mind and muscle are thus indissolubly connected, we find that the motor cell and the mental cell, so far as we can at present distinguish them, are everywhere mixed up. Every sense impression sent up to the brain from without stimulates muscle cells and mental cells at the same time. In some cases they rouse a muscle movement; in other cases a mental act. Reflex or automatic action can take place in both cases without any will power being exercised at all. The larger and more complex 'neurons' of the brain cortex, each with numerous and far-reaching branches, are probably motor in their chief purpose, and control muscle. The smaller, but infinitely more numerous, neurons are probably chiefly mental in purpose, and control mind. But both are inextricably blended and connected, just as muscle and mind, as we have seen, are connected.

"Mental action long persisted in causes fatigue, precisely as muscular action does. Especially the act of continuous attention either to one's own thoughts or to objective impressions produces such fatigue. In such a case the muscles of the special sense organs are kept on the strain, and, small as they are, this causes great exhaustion. Ribot has shown conclusively that attention is absolutely analogous to a muscular act, and has the same results."

The mechanism by which mind and voluntary muscles are influenced and set in motion has been already fully described. It only remains to explain how the motor nerves terminate in the muscles and how muscles move.

The generally accepted belief is that the motor nerves terminate in the muscles by means of separate end plates or expansions (Plate cxxxiv., Fig. 6, p. 754).

Professor L. S. Beale is opposed to this view. He maintains that the motor nerves, like the sensory, terminate in networks or plexuses, which are continuous, and which consist of the most delicate nerve fibres. He says:[1] "Not only have I never been able to discover the 'end' of a nerve fibre in any 'end organ' or other situation, but, from what I have seen of the disposition of nerve fibres generally, I believe I am fully justified in giving the opinion that no such arrangement exists, or ever has existed, in living nature.

"I have studied the peripheral distribution of nerves on sensitive surfaces, as of skin, and mucous membrane, the nerves distributed to special sensitive organs and to different kinds of muscular tissue, well situated for thorough examination, so that no thin artificial sections are required, or are possible, seeing that the structure is extremely thin and perfectly transparent. Each consists of a very thin layer much thinner than any section, and includes all the structures which the delicate, membranous, muscular expansions contain. . . .

"In the very thin membranous bladder of the common frog, and of the little green tree frog, there are in every part, just beneath the very thin layer of epithelium, and upon and amongst the multitudes of contractile fibres of involuntary unstriped muscle, delicate nerve fibres forming networks; and here and there some of these fibres are followed to and from small trunks of 'dark bordered' nerve fibres, with one of the subdivisions of which a delicate fibre is seen to be connected. Many of the fibres have been traced to small collections of ganglion cells, situated here and there on the bundles of the collections of dark-bordered nerve fibres.

"On the surface of the beautiful and very active, but delicate, mylo-hyoid muscle of the green tree frog, which consists of two layers of very narrow, transversely-striped fibres of voluntary muscle, there appears—when distended during life, or extended after death, and properly prepared for examination—a very thin, transparent, extensive network of nerve fibres, the meshes of which are wide apart, while the 'fibres' consist of exceedingly delicate fibres, many of which are seen to bifurcate at the angle or corner of one of the meshes, and cannot be followed far without our noticing a division, each branch of which may be traced for a short distance, when it again divides. Thus are formed the ultimate networks of excessively fine nerve fibres, distributed to every part of this very thin, extensive, membranous muscle, which in many places consists of only one single layer of parallel, very narrow, muscular fibres, over which the nerve networks are seen. Many individual ultimate nerve fibres of the networks have been traced for considerable distances, and their divisions and subdivisions followed, as they ramify over the surface of individual muscular fibres. No 'nerve end' or 'end organ' is to be found in any of my specimens, and to me it appears certain that there is no 'end plate' or 'end' of any kind on the surface, in the substance, or in any way connected with any contractile muscular fibre in these naturally excessively thin extensive expansions of muscular tissue, so exceptionally favourable for the demonstration and determination of the ultimate arrangement of the finest nerve fibres, and their exact relation to involuntary and voluntary muscular tissue.

"Now, in the above preparations of involuntary and voluntary muscle, the distribution of the finest nerve fibres is upon the same plan—every one of these 'finest fibres' is compound, and consists of two or more, and where one leaves another at right angles, a fibre can be followed which runs horizontally beyond the point where a fine

[1] "Vitality," by Lionel S. Beale. London, 1899, p. 47, &c.

fibre diverges to take part in the formation of the network; and at the angle this divergent fibre can always be seen to be composed of at least two fibres, which run in opposite directions along the horizontal fibre. In other words, never is seen an undoubted single fibre leaving another fibre at an angle, for at the point where every fine fibre joins the horizontal fibre there is a triangle, and at the point of 'junction' there are invariably at least three fibres—and really, I believe, more—or at least more than one line along which individual nerve currents may pass.

"In both preparations, and in many others, fine nerve fibres can be traced to the capillary vessels, and not infrequently two fibres are seen running close to one capillary.

"In short, in the above specimens (and I have examined hundreds), after poring over the best for hours at a time, again and again, I can arrive at no other conclusion than that there are wide peripheral networks of dark-bordered nerve fibres, and peripheral networks of the finest ultimate nerve fibres, every fibre of which networks *is a compound fibre*. . . .

"There are hundreds of preparations of striped muscle in which the fine nerve fibres I have described are undoubtedly without a single fibre exhibiting an 'end plate' or anything that could be mistaken for an end plate.

"I therefore regard it as certain that in the most active and most beautiful of all batrachia, and in all mammalia and birds, muscular fibres perfect in structure, quick and prompt in action, the contraction of which is completely under the control of the animal's nerve centres, exist in abundance, in which the ultimate arrangement of the nerve fibres by which the muscles are directly influenced *is a network*, the fibres of which undoubtedly run on the surface and amongst the muscular fibres, and may be followed without interruption for a considerable distance, without a single 'end plate' or 'ending' of any kind being observed. And that in every case where these finest nerve fibres are seen, although two anatomically distinct fibres in what appears to be a single fibre cannot be detected, I have remarked that at the point where every fibre, however minute, is connected with others to form the 'network,' two threads pass from what seemed to be a single delicate fibre in opposite directions; and, therefore, that in each of these very fine nerve fibres or strands during life a nerve current might be passing in opposite directions—a fact strongly supporting the view that nerve fibres form uninterrupted circuits.

"Of the very large number of most delicate nerve fibres distributed over the surface of each large compound muscular fibre of voluntary muscles of insects, everywhere ramifying with the smallest tracheæ, I have no doubt as to the arrangement. As one would expect in the case of these, probably the most rapidly contracting of all forms of muscle, every contraction of which is regulated and harmonised in the most wonderful manner, we have in the nerve-muscular system of the insect a 'motor apparatus' which must be regarded as perfect. The movements of the wings in flight are far too quick to be seen by us.

"The general arrangement of the so-called pale, narrow, nerve fibres connected with ganglion cells approaches that of a very extensive network or plexus; for the ganglia are all intimately connected with one another by nerves and short nerve trunks which branch and divide and subdivide after running, as a general rule, only a comparatively short distance, thus taking part in the formation of an intricate nerve network on a very large scale, in all parts of which the 'centres'—that is, the ganglia, large, small, and microscopic—take part. The networks, or plexuses, in their general arrangement do not, however, differ from those already described as belonging to the cerebro-spinal system, and concerned in sensation, the senses, and voluntary movements.

"The ganglion cells and the nerve fibres of the 'sympathetic system,' distributed to the internal organs, heart, lungs, stomach, intestines, glands, and to the vessels—probably to all the arteries, capillaries, and veins—in every part of the body—*never sleep*. Microscopic ganglia are often seen upon very small arteries, and their connected nerve fibres form extensive networks around them, everywhere freely distributed among the numerous muscular fibres, so well known, and which form the most important constituent of the walls of every arteriole. Very fine fibres also exist just outside the walls of every capillary vessel traversed by the blood current.

"Some of the most minute of these ganglia consist of only two or three cells, the nerve fibres connected with which may often be traced to very small capillaries, by the sides of which they run, and many are often seen in the intercapillary spaces—the whole forming a lax network of ultimate nerve fibres. All are connected with oval or triangular bioplasts, the so-called nuclei.

'The compound nerve fibres of this so-called 'sympathetic system' are more often seen as highly complex plexuses, with, as already stated, small microscopic ganglia in immense numbers, than as independent separate nerve trunks of considerable length as in the cerebro-spinal system.

"Ganglion 'cells' and their fibres are constantly growing, and under certain circumstances may, I think, largely increase in number for a time, and afterwards waste, and be replaced, perhaps many times in the course of life, according as the organs and vessels which they supply temporarily advance or recede as regards their activity. And there is reason to think that from the ganglion cells the fibres may increase in length or be spun off, or, as it were,

unrolled, from the circumferential part of the 'cell.' The arrangement of their peripheral distribution, the relation of the fibres to the tissue elements, their general action, including the transmission of the current, are on the same general lines, and are governed by the same principles, as other parts of the peripheral nervous system, and are probably connected with every capillary system in every part which is dependent upon self-regulation.

"Minute ganglia of the kind may be seen upon or near all the minute arteries distributed to the heart and other internal organs. They are more easily found in the frog and in small vertebrata than in man, but they exist in us in enormous numbers, and are more widely distributed to sense and other organs, and to capillaries, than is generally supposed. Dr. Morison has recently demonstrated well-marked ganglion cells on some of the small arteries of the dura mater, where some observers have failed to discover them.[1]

"In man and the higher animals the connection between the delicate peripheral plexuses and networks of compound nerve fibres with their numerous bioplasts, by which they were formed, and through which they act, and the so-called 'cells' of nerve centres, whether ganglia, grey matter of the spinal cord, or brain, is by nerve fibres composed of a large number of very fine fibres, forming, in many cases, a firm resisting cord, surrounded by a protecting insulating sheath, consisting of highly refracting matter, principally composed of myelin, the well-known *medullary sheath* or *white substance of Schwann*, by which the so-called 'dark-bordered fibres' are characterised—large in the cerebro-spinal nerve trunks, but of less diameter in the fibres connected with ganglia, and the fibres nearing the peripheral networks, which break up, after much dividing and subdividing, into fibres continuous with the fine ultimate ramifications. Every dark-bordered nerve fibre divides and subdivides, dichotomously for the most part, as it nears the peripheral network on the one hand or the nerve centre on the other. At intervals, as well as at the points where the fibre divides, constrictions are seen, where, but for a very short distance only, the so-called axis cylinder is protected by a very thin layer only of the medullary sheath. And as we approach nearer and nearer to the very fine ultimate fibres and their bioplasts, or to some of the 'cells' of the nerve centre, all appearance of sheath or covering of any kind is lost, and the very delicate, transparent, ultimate fibres of the network, many of which, though less than the ten-thousandth of an inch in diameter, are nevertheless composed of more than one fibre or strand, by which the nerve current is transmitted and perhaps in opposite directions."

It will be seen from the foregoing that Beale disbelieves in the so-called "nerve endings" in the cerebro-spinal and sympathetic systems of nerves in the voluntary and involuntary muscles, the blood-vessels, mucous surfaces, glands, &c.; the arrangement, according to him, consisting in every instance of delicate nerve plexuses, simple or complex according to circumstances. There are, in his opinion, no nerve endings in the literal acceptation of the term—that is, single, non-continuous nerve fibres (Plates cxxxvi. to cxli., inclusive, pp. 757 to 765).

While Beale claims continuity of nerve fibres in the periphery of the nervous system, he denies their continuity in the brain and spinal column. There is clearly inconsistency here. Recent workers claim continuity, and properly, for the nerve fibres of the central portions of the nervous system, as witnessed in nerve cells, ganglia, neurons, &c. It would be difficult to over-estimate the importance of the relations existing between the brain and nervous system and the voluntary and involuntary muscles in the higher animals and in man. They are mutually interdependent. While the brain and nervous system regulate, within limits, all muscular movements, there are good grounds for believing that certain muscles—the muscles of organic life, for example, including those of the heart, blood-vessels, alimentary canal, bladder, uterus, chest, &c.—are endowed with inherent or fundamental movements, rhythmic in character.

These muscles are not under the influence of the will, and continue their work with unerring regularity during the waking and sleeping state from the cradle to the grave. The heart beats regularly even in the anencephalous or brainless fœtus. It also beats regularly when cut out of the body, deprived of its blood, and placed in an exhausted receiver. The vermicular movements of the intestine continue for some considerable time after death. The voluntary muscles fall under a different category. They are known to be directly influenced and set in motion by efforts of the will. These muscles, however, often act involuntarily and rhythmically, in cases of insanity, for example. They do practically the same thing from force of habit, as exemplified in ordinary walking, swimming, flying, and other co-ordinated, associated movements. When voluntary muscles have been trained to perform certain movements at stated intervals, the nerve element can be eliminated without invalidating (vitiating) or destroying the movements.

The muscles of the limb of a decapitated frog can be made to move freely on or off the body, and the muscles of a shark respond to stimuli days after the shark is dead, and even after they have been removed from the body, as I have verified from actual observation—all which points to an independent power of motion inhering in muscles apart from nerve structures.

[1] "The Morison Lectures, delivered before the Royal College of Physicians, Edinburgh, 1897 and 1898," by Alexander Morison, M.D., &c. Young J. Pentland, 1899, p. 127, Fig. 39.

One of two things is certain. Either the muscles of organic life referred to are endowed with independent, inherent, *rhythmic* movements, or the nerves and nerve centres distributed to them act in an interrupted or rhythmic manner. This follows because if the nerves and nerve centres cause the muscles to act they can only do so by discharging nerve force and nerve impulses at stated intervals, and in an interrupted manner. The nerve discharge cannot, under the circumstances, be continuous. This is a fundamental point in muscular physics. My own belief is that both the nerves and muscles of organic life act rhythmically. Similar remarks may, within limits, be made of the nerves and voluntary muscles. I believe, further, that an analogy may be traced between the interrupted nerve current supplied to involuntary muscles which act rhythmically, and the interrupted current of an electrical circuit.

Nor does the analogy stop here. The voluntary muscles which act *continuously* for longer or shorter periods fall under a similar law; the peculiarity being that in this case the nerve current is constant or continuous so long as the muscular effort is put forth. It is, however, to be borne in mind that the sarcous elements of even voluntary muscles move rhythmically in waves when the muscles as a whole are brought into and kept in action (Plate lxxxiii., p. 320). There is a minor rhythm within a major rhythm, so to speak. Voluntary muscles act, or may act, in a particular direction for some considerable time, but sooner or later their action is interrupted or discontinued; and even when they are acting continuously as a whole, their sarcous elements are acting interruptedly at intervals. The sarcous elements rest, work, and are fed, by turns.

In the case of the involuntary muscles which act rhythmically the nerve current is an interrupted current. In the case of the voluntary muscles which act continuously for a given period the nerve current is a continuous or non-interrupted current.

The interrupted and non-interrupted nerve currents in all respects resemble electric currents.

It is quite within the possibilities that all nerve action as well as all muscular action is interrupted. The workings of the brain are non-continuous in the sense that intellectual efforts produce fatigue analogous to muscular fatigue, and must be demitted from time to time. The mental states known as emotions are interrupted and rhythmic in their nature. Sleep is as necessary for the brain as for other parts of the body.

Beale is of opinion that nerve discharges and currents can be sent along the nerves in any given direction, *and in certain cases in opposite directions*. He bases his convictions on the general anatomy and microscopic anatomy of the nervous system. He remarks: "We may see dark-bordered fibres becoming continuous with or gradually 'breaking up' to form the delicate fibres of the network or plexus of very fine nerve fibres, every one of which can be followed over a small area of tissue; until here and there another dark-bordered nerve fibre is seen, which is also continuous with fine fibres, and which passes away from the network of fine fibres in an opposite direction. *In fact, a network of ultimate nerve fibres between, and continuous with, a dark-bordered fibre which apparently passes into it on one side, and one which passes away from it on the other.*"

The fact that the finest terminal nerves in the nerve plexuses pass in opposite directions, and the belief that opposite nerve currents pass through the ultimate nerve fibres, raise an important question in connection with the movements of both the voluntary and involuntary muscles.

I have for very many years—in fact, since 1872—held that all muscles are invested *with a double power*, whereby they can, in the case of the involuntary hollow muscles, alternately open and close, and, in the case of the voluntary muscles, alternately elongate and shorten. This double action, it appears to me, inheres in the substance of the muscles, and requires for its regulation in the higher animals two sets of nerve fibres and two kinds of nerve currents. If this view be not adopted, the muscles in every part of the body, seeing they are arranged in groups which act in opposite directions, must antagonise each other instead of working harmoniously to a given end.

The flexor muscles must forcibly drag out the extensor muscles, and the reverse; the muscles of the bodies of the hollow viscera must force the passages of their muscular sphincters, and the muscular chambers of one half of the heart when they close must forcibly open the muscular chambers of the other half. In a word, half the muscles of the body must wage war against the other half, and result in a ruinous waste of power. An impossible state of matters is produced.

One, however, looks in vain for the muscular duels which, according to prevailing views, everywhere exist. Instead of opposing muscular factions one witnesses everywhere the most perfect harmony in muscular action—groups of associated muscles moving simultaneously and in the most perfect order to bring about desired or premeditated results.

A careful examination of the volumes of the so-called opposing muscles in the viscera goes far to prove this contention.

The thin weak muscles forming the auricles of the heart cannot possibly forcibly distend or open up the firmly-contracted, thick, powerful muscles of the ventricles of the heart (Plate lxxxv., p. 325). Neither can the thin muscular coatings of the bodies of the stomach, rectum, and bladder forcibly distend or open up the thick and

powerful muscular masses constituting the sphincters of these viscera (Fig. 67, p. 326). It follows that the sphincter muscles must open spontaneously by a vital act. The opening movement is aided but not caused by elasticity. Similar remarks may be made regarding the flexor and extensor muscles of the body. In no case do the flexors forcibly drag out the extensors when a limb is flexed, or the reverse when a limb is extended (Plate lxxxiii., Fig. 4, p. 320).

The volume of the flexor and extensor muscles is as nearly as may be equal—allowance being made for the more favourable physical conditions under which the flexor muscles act. It is not intended that the flexor and extensor muscles should be opposed to, and act against, each other; their primary function is to move the bones, which constitute the levers of the body, and which perform the mechanical work of the body whether that work be the ordinary work of daily life or locomotion. As is well known, the flexor and extensor muscles are at rest when the limbs are extended in more or less prone positions.

It is true that when hollow muscles close and long muscles shorten they do so suddenly and with great vigour, but this circumstance affords no proof that the opening and elongating movements are not fundamental, independent, and vital in their nature. The plant (*Volvox globator*) closes its water vacuoles suddenly and opens them more leisurely; the heart of the chick has a similar action. In these neither muscles nor nerves are present. They are in both instances inherent, independent, vital movements. That the bodies and sphincters of the hollow viscera act independently and by an inherent vital power is evident from this. In micturition, when there is next to no urine in the bladder, the little there is can be extruded by an effort of volition, and by waiting until the sphincter of the bladder opens. When once the rhythmic movement between the body and sphincter of the bladder is established, the rhythm goes on when no urine is present, and irrespective of the will. The same thing happens after defæcation as between the rectum and its sphincters. The latter movement is well seen in the horse. The opening and closing movements do not stand to each other in the relation of cause and effect.

Too much attention cannot be paid to muscular action in the higher vertebrates and in man. His life depends on it. It is necessary in seizing his food, in swallowing and digesting it, and in getting rid of the detritus or waste. It is necessary to the circulation of his blood and the nourishing of his tissues. It is necessary to his breathing. By the aid of muscles he takes in fresh air and ejects foul air.

By muscular action he moves about freely on the surface of the globe. All his movements in the adult state are primarily traceable to muscle. No movement ever originates in the bones. They are auxiliary and passive organs—very important, no doubt, but still subsidiary organs. In muscle and nerve separately or conjointly inheres the power of motion, and the muscular and nervous system in the mammalia are mixed up and blended in the most extraordinary manner—so much so that in no part of the body is the one found without the other. The two are mutually interdependent. As a consequence, even the most complex animals may be regarded as consisting mainly of a muscular mass which can move or be moved in all its parts and particles with the most perfect ease and precision.

The very intimate connection existing between the muscles and nerves reduces the body to a fluctuating, pulsating, living mass essentially rhythmic in its nature. This statement may excite surprise, but it is nevertheless true. The breathing is rhythmic, the circulation is rhythmic, the digestion and assimilation are rhythmic, the œsophagus, stomach, bowel, rectum, bladder, and uterus act rhythmically, the voluntary muscles elongate and shorten rhythmically. The production of voice, hearing, and seeing are rhythmic; crying, sighing, sneezing, and hiccoughing are more or less rhythmic. The emotions are rhythmic. Reproduction is particularly so. Walking and dancing are rhythmic, and the whole being is thrilled to its centre by the universal power of music, which is, so to speak, the rhythm of rhythms. The fact that the highest and most complex organisms are made up of a great many different tissues and systems, each independent within limits, does not affect the question. The differentiation—the division of labour—is so perfectly controlled that no hitch can possibly occur so long as the organisms continue in health. The most complex organisms do not differ from the most simple as far as mere life is concerned. Both are composed of living particles, the particles having lives of their own. It is the aggregate life of the particles which forms the life of the individual. The particles live and die during the life of the individual, so that there is a particular life and a general life, a particular death and a general death. The particular life pertains to the living particles, the general life to the living organism; the particular death to the death of the particles, the general death to the death of the organism. When general death occurs the different parts and particles of the body are found to die at different periods. The nerves die before the muscles, the voluntary muscles die before the involuntary muscles. The heart, in the case of death by hanging, has been found to live and beat for a quarter of an hour after life has been pronounced extinct. This fact was first discovered by my friend Dr. Sidey, who sent me his original notes in the case of the murderer Chantrelle, who was executed at Edinburgh.

In cases of hanging it is not an uncommon thing at the present time to take sphygmographic tracings of the dead man's pulse.

The fact that all organic living bodies are composed of living particles, and communities of particles, compels us to regard them as living masses with a certain degree of oneness about them. The simpler the particles composing an organism, and the greater the facility for nourishing the particles, the longer the life as a rule. Given the necessary conditions of climate and soil, a tree can live for a thousand or more years. This an animal can never do. Its parts are too complicated and its food is too precarious.

If the highest organisms be considered as living, sensitive, independent, moving masses, which have not only a place in nature but a function or duty to discharge, many of the theoretical statements made regarding irritability, reflex action, excitability, instinct, negative pressure, tonicity, automatism, &c., will disappear from physiological literature.

Modern physiologists for the most part regard plants and animals as mere machines, which are goaded into activity by mechanical stimuli of some sort. No allowance whatever is made for the life, and for the original endowment and design which the life represents. Living things, according to them, are at the mercy of the elements. This view is negatived by the fact that in their formation and growth, and during their whole lives, they are superior to the elements, which they select and reject at pleasure. Living things exercise this power of selection with such discrimination that it is impossible to regard any function performed by them as in any sense haphazard. Life is a prime mover—a master power. In every instance it controls the elements. In no case is it the sport of the elements. The theory of irritability as applied to living things is misleading and mischievous. It ignores, or largely ignores, the power possessed by them of moving independently in particular directions and to given ends.

Those who hold that all function is the result of direct or indirect stimulation put the cart before the horse. They give to non-living, mechanical matter a power only possessed by vital living matter. They assign non-living a higher place than living matter—they also erroneously put physical force above vital force.

I am well aware that the physicists and chemists of the present day in many cases maintain that there is only one kind of force—namely, physical force. With this view I wholly disagree. There is no proof that there is only one force in the universe. The proof is all the other way. No chemist or physicist has yet succeeded in manufacturing anything approaching a living thing—even the most rudimentary. There is no well-authenticated case of spontaneous generation. Every plant and every animal that lives is, so far as is known at present, the product of a spore, seed, germ, or egg. A precursor or parent can always be discovered. The question might here be put, How came life into the world? The same question, however, might be put as regards matter. The existence of life and matter in the universe must be postulated—taken for granted—accepted as ultimate facts. There is no getting behind them. The physiologist and physicist have to do not with creation but with a created universe—a universe consisting of organic and inorganic matter and of vital and physical force.

The human intellect can only deal with life, matter, and force as they exist, and as they are known to us. Speculations regarding the origin of matter, force, and life, though interesting, can never be profitable. They are attempts on the part of the finite to grasp the infinite.

CONSCIOUSNESS AND MEMORY

The authors of "The Unseen Universe," in developing their argument, "the principle of continuity," refer to consciousness and an organ of memory in the following terms:[1] "Individual consciousness is in some mysterious manner related to, or dependent upon, the interaction of the seen and unseen. . . . It is less permanent than matter, inasmuch as such consciousness frequently departs from the universe for six or eight hours and then returns to it again. In one sense this is unquestionably true, while, however, there is a potential or latent consciousness or possibility of consciousness that remains behind. . . . Mind cannot exist without matter, while matter can and does exist without mind. . . . The connection between mind and matter is a very intimate one, although we are in profound ignorance as to its exact nature.

"The intimacy of this connection is almost universally admitted by modern physiologists. Just as no single action of the body takes place without the waste of some muscular tissue, so, it is believed, no thought takes place without some waste of the brain. Nay, physiologists go even further, and assert that each specific thought denotes some specific waste of brain matter, so that there is some mysterious and obscure connection between the nature of the thought and the nature of the waste which it occasions. In like manner memory is looked upon as dependent upon traces, left behind in the brain, of the state in which it was when the sensation remembered took

[1] "The Unseen Universe," by B. Stewart and P. G. Tait. London, 1901, p. 77, &c.

place. Thus Professor Huxley in his Belfast address (1874) tells us: 'It is not to be doubted that those emotions which give rise to sensation leave on the brain changes of its substance which answer to what Haller called "*vestigia rerum*," and to what that great thinker David Hartley termed "Vibratiuncules." The sensation which has passed away leaves behind molecules of the brain competent to its reproduction—"sensigenous molecules," so to speak—which constitute the physical foundation of memory.' . . .

"One of the essential requisites of continued existence of the individual is the capability of retaining some sort of hold upon the past: and, inasmuch as we are unable to contemplate such a thing as a finite disembodied spirit, it is evident that this hold implies an organ of some sort. This we conceive to be a perfectly general proposition. We do not limit ourselves in making it to any particular arrangement of bodily form, or to any particular rank of finite organised intelligence. From the archangel to the brute we conceive that something analogous to an organ of memory must be possessed by each. . . .

"There must in the first place be an organ connecting the individual with the past, and in the next place there must be such a frame and such a universe that he has the power of varied action in the present."

That there is a physical basis for consciousness and memory goes without saying. It were not otherwise possible to account for many of the operations of the mind, and for the education and progress of the individual and of the race.

The sudden blow of a bludgeon on the head deprives the person struck of consciousness and memory for a longer or shorter period, according to the severity of the blow. The molecules of the brain have been disturbed—suddenly displaced—a temporary abnormal condition has been produced known as concussion of the brain. The differentiated brain molecules have not, however, been destroyed by the blow, and after a while return to their normal state; and when they do return, consciousness and memory also return. This connection between the brain substance, consciousness, and memory is obvious, and of the most intimate description.

Again, in cases of softening of the brain, one of the first symptoms is a partial failure of memory. As the softening advances, memory disappears. In complete softening all the intellectual faculties suffer, loss of consciousness ultimately supervening. Here, too, the connection between brain substance, consciousness, memory, and mind is of the most striking and convincing character.

It is difficult to resist coming to the conclusion that all living things, plant and animal, are endowed with a low form of cognition which enables them to distinguish between things, and to retain their places in nature. This rudimentary power of knowing, closely allied to consciousness, as we understand it, does not require a nervous system in the ordinary sense. Plants and animals certainly feel, and knowing and consciousness of a kind is, as a rule, associated with feeling. The sensitiveness of plants, in many cases, greatly exceeds that of animals. Darwin has shown that plants respond to stimuli which would have no effect whatever even on the most sensitive animals.

The movements of sensitive and insectivorous plants, and of low animal forms, with no visible nervous system, present many of the peculiarities of spontaneity and volition. Animals with a rudimentary nervous system, but possessing no brains, move voluntarily. The star-fish is an example. It would seem, therefore, that what is practically a nervous system exists in plants, and in the lowest animals (amœba, paramecia, &c.), and that consciousness and memory are mere questions of degree. In other words, there are good grounds for believing that consciousness and memory are fundamental endowments not confined to the higher animals and man. There is, and always has been, a tendency to attach too much importance to nervous matter and to brain in their visible and differentiated forms as compared with other living matter. The fact that the lowest plants and animals can exist, grow, reproduce themselves, and perform all the functions of life in the absence of a visible nervous system, goes far to prove that the homologue or representative of a nervous system exists in some form or other.

It can scarcely be otherwise. Plants and animals must be endowed with powers which ensure their preservation, development, and progress, and some form of cognition, consciousness, and memory is, under the circumstances, called for. The existence of these powers in the higher and highest animals is in favour rather than subversive of similar but modified powers in the lower and lowest animals. Essentially the same elements and forces enter into the composition of plants and animals, and differentiation is a mere development from common materials. The statement that traces of a rudimentary cognitive faculty, consciousness, memory, &c., exist in sensitive plants and animals devoid of a nervous system as we know it, should occasion no surprise, since not life only, but the continuation and transmission of life, demand some such powers.

It is known that in reproduction like begets like; a remark which applies to the body and to all the tissues of the body. It also applies to every form of mental peculiarity. Continuity of organisms and of structures implies hereditary transmission.

It ensures atomic and molecular resemblances and modifications, which make for progress in the individual and in the race when that is desirable and called for. It would not be possible to develop intellectual powers from

living materials in which there was no trace of feeling, consciousness, and memory. Further, education in all its forms, physical and mental, proceeds on the assumption that it is possible to modify, train, and improve the molecules and cells which form the tissues, the nervous system, and the brain. Training begets, so to speak, molecular habits which many believe are transmitted. Tissues which are trained improve. Regarding the nervous system and brain as tissues, this remark holds true of the intellectual faculties. The power of knowing has its roots in the lower and lowest animals, and is represented in common parlance by the loosely-defined and unsatisfactory term instinct, which means everything or nothing.

Habit may be defined as the accumulated knowledge and experience of the individual. It is in no sense a blind power involuntarily exercised. The mode of its acquisition forbids such an assumption. It is a fundamental power, but it is also a developed and cultivated power.

It will be seen from the foregoing that training is at once a physical and a mental act, that it has a physical basis, and that the cultivation of the individual inevitably results in the improvement of the race.

This holds true of everything trained, plant and animal alike. Domestic plants and animals owe their peculiarities and advanced condition to training extending over long periods. The changes induced by training are, in some instances, so considerable that it is difficult to trace a cultivated plant or animal to its original stock. This is especially true of cultivated vegetables and flowers, and of such animals as pigeons. The sure method of discovering the primal type is to permit them to breed back by neglect. Cultivated plants and animals, if left to themselves, go back to their originals sooner or later.

Where man interposes his intelligence in cultivating plants and in breeding animals, a temporary advance is secured, which, as a rule, is lost when the plants and animals cease to be cultivated.

The cultivation of plants and animals by man is brought about by *artificial* selection, and it is an open question, notwithstanding all that has been written to the contrary, whether there is such a thing as *natural* selection. It is more than probable that the improvement in plants and animals which occasionally occurs is not due to selection but to the operation of natural laws.

When plants and animals improve by cross-fertilisation, the chances are they do so under the operation of certain laws, to which they are amenable, but which they in no sense control. This would seem to follow especially in the case of plants where the male and female elements are situated on different individuals. It would also hold true, within limits, of animals, where desire for the most part gets the better of judgment in selecting mates. Even in man mating is not, in many cases, the result of unbiassed natural selection. He chooses his bride, in quite a large number of instances, not because she possesses superior physical and mental endowments, but because she is wealthy, her position in society wields power, &c. If men were as careful in their matrimonial arrangements as in their breeding of stock, there can be no doubt that the advance of the human race would be much more rapid than it has hitherto been, or is likely to be under modern social conditions.

While artificial selection by man, where intellect comes directly into operation, is well understood, it is otherwise with the so-called *natural* selection, where the intelligence, even if it be admitted, is extremely limited. While the lowest plants and animals are endowed with fundamental powers which secure their continuity and well being, they do not, in my opinion, exert selective powers in the sense in which Darwin uses the term. The power of selection, there is reason to believe, is reserved for the higher animals, and it is largely, if not exclusively, artificial in its nature. The results of artificial selection can be seen by any careful observer. They fall within individual experiences and the historic period. Natural selection, on the contrary, as applied to plants and animals by Darwin, does not occur during the lives and experiences of individuals or historic epochs. It, as a matter of fact, requires unlimited modifications in unlimited time. The making of species by natural selection practically deals with a matter of which the human mind, because of the nature and immensity of the subject, is profoundly ignorant. If it takes a hundred or a thousand years to make a species, what proof can we have that it was made within the periods stated? If modifications in plants and animals are continually taking place by so-called natural selection, and what are virtually new plants and animals are being manufactured during the ages, what shall we say of the stability and persistency of types? The human race has not varied to any appreciable extent for the last seven or eight thousand years, and we have examples of plants and animals in the present day, originals of which occur in fossil form. Of course it is easy to claim unlimited time and modification in explaining the varieties of existing plants and animals, but are we entitled to do so? What can neither be proved nor disproved must always remain a subject of speculation and hypothesis.

THE SENSORY ORGANS DEVELOPED FROM WITHIN AND NOT FROM WITHOUT

Much discussion has arisen as to how the sense organs are produced. Some aver that they are the result of external stimulation and environment: that light makes the eye, sound the ear, smelling particles the olfactory organs, sapid substances the taste organs, and physical surroundings the sense of touch. It is attempted to refer the sense organs in the higher animals to evolution, natural selection, and the differentiation of rudimentary structures, such as sensitive hairs in plants, and sensitive hairs and feelers, antennæ, &c., in the lower animals. This view presents an insurmountable difficulty. It assigns to external surroundings the power of forming the organs of living animals, and deprives the latter of the exercise of the prerogative of life. It practically leaves everything to chance.

The other view, which I believe to be the correct one, assigns to animals the power of growing and developing in certain directions, and of forming their own sense organs apart from external surroundings, environment, and artificial stimulation. Each animal, according to it, is the outcome of pre-arrangement and design, and each is supplied with the precise number and kind of sense organs which are suited to its requirements as an independent entity. Nothing, not even the most trivial detail, is left to chance. The animal, be it simple or complex, great or small, high or low, is exactly fitted for the niche it is to occupy in nature: it is provided with powers which make it superior to its surroundings. The latter view is very fully borne out by the development of the higher animals *in utero*.

In the fœtal condition the environment is peculiar, and wholly unlike that met with in the physical universe. The conditions which are said to form the sense organs are practically absent. Thus the eye is developed in darkness, the ear in silence, the nose apart from odoriferous particles, the mouth in the absence of sapid substances, the skin being in contact for the most part not with dead, but living surroundings. Further, the sense organs are developed in anticipation of the function they are finally to discharge. In other words, the eye evolved in darkness is specially formed to deal with light and the objects which the light reveals; the ear evolved in silence is specially formed to deal with surrounding bodies near and remote; the nostrils evolved in the absence of smelling particles are specially formed to deal with smelling substances when they present themselves; the tongue and palate evolved in the absence of food are specially formed to deal with it when the proper time arrives; the skin bathed in homogeneous fluids or in contact with living substances is specially formed to deal with a great variety of inanimate materials with which it comes in contact after birth.

All the organs of sense are material in their nature, and act upon something outside of themselves which is also material. They are essentially touch organs, and proceed by way of feeling and impact; the latter being of the most dainty and refined description possible. It is a case of action and reaction, characterised, in some instances, by a certain degree of chemical change.

The eye is provided with vast numbers of exceedingly delicate rods and cones, and the ear with an infinity of graduated Cortian rods which, by sympathetic vibrations acting on the optic and auditory nerves, enable us to detect the undulatory movements of the ether and atmosphere which are the true objectives of seeing and hearing. Seeing and hearing have a physical basis. Strictly speaking, there is no such thing as sound or light. "These are mere names for physical impressions produced upon special nerves by the energy of undulatory motions of certain media."

The sense organs (as indicated) are developed independently from within, in virtue of life and growth in special directions, and not from without by environment or the extraneous substances which constitute it. All the organs and systems of animals are formed in the same way. The respiratory, circulatory, lymphatic, nervous, muscular, osseous, and glandular systems are all developed from within. The animal requires to be perfected *in utero* before it can discharge its functions as an independent being in the universe. If the sense and other organs and systems of animals owed their development and existence to externalities, and not to the life, power of growth, and directive agencies of the parent, or parents, it is quite obvious that living things would never be formed, unless, indeed, we believe in spontaneous generation, which I regard as impossible. Some will, no doubt, maintain that a plant or an animal once formed is to be placed in a different category from one in process of development, and that the perfected individual is irritable, and a prey to environment which modifies and controls it. I am wholly opposed to such a view. I do not believe in irritability as applied to plants and animals, and I refuse to assign to environment, powers exerted by life and life alone. The adult plant and animal are as much under control, and law, and order as the immature plant and animal: the adult individuals are not abandoned as soon as they are matured. On the contrary, they are endowed with new and increasing powers to enable them to adapt themselves to altered and ever-varying circumstances. The modifications, whatever their nature, in every instance come

from within. The thin-skinned, thin-leaved plants of temperate zones develop in the tropics thick integuments and fleshy leaves. The latter condition enables the plant to store up and retain moisture. Similarly, animals modify their integumentary appendages to adapt themselves to their surroundings. In the Arctic regions birds and beasts develop a dense covering of feathers, down, and fur, and in the case of seals, walruses, and whales a thick layer of integumentary fat or blubber; in the tropics, on the contrary, the skin is sparsely provided with feathers and hair, and, in some cases, hairless, thickened, and thrown into great folds as in the pachyderms, of which the elephant, rhinoceros, and hippopotamus are good examples. The living thing, plant and animal, is in every instance to be credited with whatever modifications occur in it. The same power which presides over and regulates development, presides over and regulates the entire life of the adult plant and animal. What is termed instinct is simply life and law asserting themselves, and this happens either with or without a nervous system.

The sense organs are God's special endowments to His creatures, given for their protection, enjoyment, and general well being. They are very properly spoken of as the gateways of knowledge, as it is by their aid that the higher animals obtain their knowledge of external nature as a whole. Without them the higher animals would have no advantage over the lower ones. The God-like powers possessed by man are largely due to the number and perfection of his sense organs. They connect him with the matter of the universe near and remote. The eye, aided by the telescope and microscope, brings him into relation with the infinitely great and the infinitely little—with the stupendous heavenly bodies, some of them immeasurably remote, and with the inexpressibly minute particles of matter which only the highest powers of the microscope can reveal, and which, in order to be seen, must be viewed at very close quarters; the ear connects him with sounding bodies vibrating in space, it may be, miles distant; the sensitive skin connects him with the grosser substances in his immediate vicinity; the nostrils connect him with the finer smelling particles floating in the air; and the mouth connects him with the sapid substances which form his food and drink. All animals up to man, and man himself, are masters of the situation as far as externalities are concerned. The organic kingdom was formed subsequently to the inorganic one, and plants and animals are amply endowed to enable them to take full advantage of the physical universe in which they are placed, and which was duly prepared for them by the Beneficent Being Who made and rules the universe. While it is true that plants and animals cannot control their growth, it is equally true that the growth of both is controlled by the First Cause. A man may not add a cubit to his stature, but he cannot grow otherwise than in the Divine image. If he cannot voluntarily develop sense organs, still less can environment and the inorganic kingdom develop them for him. The configuration of man as a whole, and the development of his sense organs in particular, are all traceable to design. A man without sense organs would be in no way adapted to the world he inhabits. He depends on them primarily for all the knowledge he possesses of the inorganic kingdom. The sense organs are structural units of the highest importance, and can readily be located. They have also great physiological significance. They have an objective and a subjective side; the objective refers to changes which occur in the outer world, the subjective to changes which occur in the inner world. There is the matter felt and the matter feeling. The organ of the inner man finds its foil or suitable object on which to act in external nature. The sense organs have no significance apart from the objects on which they are calculated to operate. Fishes living in the water of dark, subterranean caves gradually lose their power of seeing. In order to understand to what an extraordinary extent we are dependent on the sense organs it is only necessary to contemplate the helpless condition of the blind and deaf. An individual born blind and deaf is incapable of leading a separate, independent existence. If left to himself he would inevitably perish.

§ 232. Environment. (The Production of the Eye.)

Mr. Romanes attributes the formation of the eye to *natural selection*, and maintains that the eye affords no proof of design. He thus states his case:[1]

"On the hypothesis [that is, of its production by the aid of natural selection] we have the eye beginning, not as a ready-made structure prepared beforehand for the purposes of seeing, but as a mere differentiation of the ends of nerves in the skin, probably in the first instance to enable them better to discriminate changes of temperature. Pigment having been laid down in these places the better to secure this purpose, the nerve-ending begins to distinguish between light and darkness. The better to secure this further purpose, the simplest conceivable form of lens begins to appear in the shape of small refractive bodies. Behind these, sensory cells are developed, forming the earliest indication of a retina presenting a single layer. And so on, step by step, till we reach the eye of an eagle. . . .

[1] "Thoughts on Religion," p. 62.

"Let us assume that natural selection has been satisfactorily established as a cause adequate to account for all these effects. . . . What follows? Why, that each step in the prolonged and gradual development of the eye was brought about by the elimination of all the less adapted structures in any given generation—that is, the selection of all the better adapted to perpetuate the improvement by heredity. Will the teleologist maintain that this selective process is itself indicative of special design?"

The foregoing account of the evolution of the eye by Romanes is a good example of the *petitio principii* or begging of the question at issue. It is not supported by facts of any kind. According to his view the body should be eyes all over wherever there are nerve-endings and skin. Why should the eyes be confined to one part of the body in the higher animals? Romanes has no authority for asserting "that each step in the prolonged and gradual development of the eye was brought about by the elimination of all the less adapted structures in any given generation."

The position taken up by Romanes, if admitted, would apply to all the other sense organs, and to all the tissues of compound organisms.

It is quite true that in the lower animals there are various grades of eyes, and of the other sense organs. There is also a differentiation of the skin, or common covering of the body, in which the sense of touch resides, and from which all the sense organs spring. A gradual elaboration and advance in the sense organs in the lower animals and in man, however, does not indicate inferiority, or imperfection, or want of design, in these structures. Each is accurately and perfectly adapted to the function to be discharged by it. Gradation and gradual development does not mean failure or weakness in any link of the ascending chain. The links become larger and stronger, but there is no breach of continuity in structure or function. A study of the skin is instructive in this connection (see Plate cxxxvi., p. 757).

The skin, as already explained, is presumably the parent of all the senses, and the differentiation which results in the production of the sense organs begins and makes considerable progress in the skin itself.

The sensitiveness of the skin varies in different regions of the body. The ventral surface is more sensitive than the dorsal. The tips of the fingers, the lips, and the apertures of the body are specially sensitive. In the most sensitive parts of the body special touch bodies or corpuscles are developed, and are known as end bulbs, Pacinian bodies, &c. (A Pacinian body in some respects resembles the eye of the higher animals.)

The amount of information given by the sense of touch is very great. It enables us to distinguish between hard and soft bodies, cold and hot bodies, smooth and rough bodies, &c., &c.

The power of feeling, which has made considerable progress in the skin, is differentiated in the sense organs, especially the rudimentary ones, such as the organs of taste and smell. The various modifications of the skin and of the sense organs, resulting in increased sensitiveness to external impressions, represent so many adaptations of means to ends. The skin and the sense organs developed from it are given to living creatures as a protection, and to connect them with the outer world and the substances it contains, whether near or remote. The senses enable the individual to feel external nature in its many forms—gross matter and the finest ethereal particles—and the more perfect the senses the greater the amount of information conveyed. The skin and the sense organs may be rudimentary or highly developed, but in every case they are suited to the requirements of the organism, and are perfect of their kind. They are never accidental structures, and there is no proof that they are not specially designed structures. They are each adapted to their peculiar work. It happens occasionally that similar structures apparently perform different functions. This is the case in certain hair-like processes which act as feelers for the skin, the ear, eye, &c. They deal with vibrations of various kinds, and fall under that category. They form the sensitive hairs of insectivorous plants and of several of the lower animals, the *true* rods of Corti and sounding hairs of the ear, the *rods and cones* of the eye, &c. The processes referred to have a common basis structurally and functionally, and indicate adaptation and design.

While Romanes denies design in the evolution of particular structures and the details thereof, such as the eye, he admits it in creation as a whole or in the aggregate. Logically the details or particulars make up the aggregate or general conclusion.

"General conclusions (he states) can only be based on the accumulation of special conclusions. . . . Chaos in the universe means chaos in detail. Conversely, cosmic order is based upon orderly minutiæ." [Certain modern Darwinists wholly repudiate design in nature.]

The following is the conclusion arrived at by Mr. Romanes: "If the argument from teleology is to be saved at all, it can only be so by shifting it from the narrow basis of special adaptations to the broad area of nature as a whole. And, here, I confess that to my mind the argument does acquire a weight which, if long and attentively considered, deserves to be regarded as enormous. . . . The argument from general law says, there must be a God, because such and such an organic structure must *in some way or other have been ultimately due to* intelli-

gence. . . . Let us think of the supreme causality as we may, the fact remains that from it there emanates a directive influence of uninterrupted consistency, on a scale of stupendous magnitude and exact precision worthy of our highest conceptions of deity."[1]

Romanes adopted Darwin's "natural selection theory" in the inorganic world (*vide* his sea-beach argument) and tried to make it fit in in the organic world, so that the origin of organic structure might be classed in the same category as inorganic ones. In this he has signally failed.

Mr. G. Henslow has substituted the word "adaptation" for "design," but it does not appear to me that anything is gained by the substitution, inasmuch as a living structure can be made to accommodate itself to its surroundings, within limits, without destroying the idea of design. A thing requires to be created or made before it can be modified, altered, or adapted. Adaptation and design are not co-extensive terms.

The word "adaptation," when employed by itself, does not necessarily include all that is included in "design." Moreover, slight changes or modifications in an organism once created do not, or should not, destroy its identity.

Mr. Henslow, in referring to the changes which plants and animals undergo during cultivation and changes of environment, traces them to protoplasm, and in this connection employs the term "responsiveness" as a synonym for sensitiveness or irritability.

I venture to take exception to the words responsiveness, sensitiveness, and irritability, as usually employed in biology and physiology, in so far as they lead the reader to believe that plants and animals are changed and modified by external influences apart from their vitality or life, which is their distinguishing feature. Plants and animals, under all circumstances, exercise a directive agency and control, and to say that a living thing is simply responsive, sensitive, irritable, &c., is only to express a half or less than a half truth. The attributing to mere externalities changes which undoubtedly occur in the living organisms themselves is alike misleading and confusing. It is a confounding of cause and effect. Living things (under guidance) adapt themselves to their surroundings, but this is quite another thing from saying that the surroundings necessitate or produce the adaptations.

The activity and the power which produce the changes and modifications inhere in the living organisms and tissues, and not in the external or dead surroundings.

Modifications once produced in the plant or animal may be transmitted and perpetuated so long as the new conditions prevail. A return, however, to the old conditions as a rule means a relapse to the original type. Variability in plants and animals is seldom or never indefinite. It does not amount to the obliteration of the original type.

Mr. Darwin thus expresses himself as regards definite variation.[2] He says: "By the term *definite action* [the italics are mine], I mean an action of such a nature that, when many individuals of the same variety are exposed during several generations to any change in their physical conditions of life, all, or nearly all, the individuals are modified in the same manner." "A new sub-variety would thus be produced without the aid of natural selection." . . . "The direct action of the conditions of life, whether leading to definite or indefinite results, is a totally distinct consideration from the effects of natural selection; for natural selection depends on the survival under various and complex circumstances of the best-fitted individuals, but has no relation whatever to the primary cause of any modification of structure."

While plants and animals under favourable conditions and improved environment advance in the scale of being, there are examples of plants and animals retrogressing without apparent adequate cause—the degeneracy beginning in themselves, and being in no sense, or to a very trifling extent, occasioned by externalities or surroundings.

This is the case in vegetable and animal parasites where the development of the organs becomes arrested. As Henslow explains:[3] "The common cow-wheat has green leaves, but it is partially parasitic by its roots. The result in this case is that there is so great a loss of assimilating power sustained by the foliage that it cannot emit oxygen gas like any ordinary non-parasitic plant. A farther condition of degeneracy is seen in the numerous greenless parasites, as broomrapes, toothwort, dodder, &c., in that they generally develop no chlorophyll at all, and are therefore entirely dependent upon their host-plants." . . . "Again, when a terrestrial plant becomes an aquatic one, its highly complicated tissues, necessary for an aërial existence, are no longer required nor produced. Degeneracy steps in, and arrests, while adaptation alters the anatomical structures."

The degeneracy in animals is in some cases even more striking. Thus Professor Carl Semper[4] states that "as a rule almost without exception, the larvæ of parasites swim or move freely about in water (leading a very unfitly

[1] "Thoughts on Religion," p. 67.
[2] "Animals and Plants under Domestication," pp. 271 and 272.
[3] "The Argument of Adaptation or Natural Theology Reconsidered," by Rev. George Henslow, M.A., F.L.S., F.G.S., &c., p. 28.
[4] "The Natural Conditions of Existence as they affect Animal Life," p. 47.

termed active life). During this stage of free locomotion the larvæ are usually high in the scale of structure. The larva of the parasitical Copepoda or Cirrhipedia (barnacles), for instance a Sacculina, is known to zoologists as a Nauplius. This animal has a nervous system, external organs of locomotion of a complicated character, a muscular system of the crustacean type, a well-developed intestinal canal, such as is found in the Nauplius larvæ of the lower crabs that are not parasites, and usually even special organs of sense—eyes. Gradually this Nauplius, after attaching itself to the gill or skin of a fish, or under the tail of a crab, loses its organs of locomotion, the greater part of its muscular and nervous system, its organs of sense, nay, often its mouth, stomach, and intestinal canal. Thus the lively crab-like larva is transformed into a shapeless sac, exhibiting no trace by which its crab-like nature can be recognised. Still the creature needs a limb by which to cling to the animal that is to be its host and provide it with nourishment; peculiar clinging organs are developed instead of the lost motor organs, and these not unfrequently also assume the office of absorbing nutriment from the host."

Another example of the degeneracy of structure and function in animals is seen in fishes which inhabit dark lake caverns. In these cases the eyes are either altogether wanting or dwarfed to such an extent as to be practically useless as seeing organs. Here disuse is followed by loss of function. Cavern fishes as a rule are not only blind; they are also pale coloured or bleached. Similar remarks apply to fishes living at great depths in the ocean, and to plants grown in the dark. Light is a potent factor, and has to be considered in structural arrangements. It happens occasionally that animals living in dark places have perfect eyes. There are cases, again, where the one sex has eyes, the other being blind. It follows from this that light does not make the eye, nor darkness obliterate it. The eye is a specially designed structure for seeing in the light, and the presence of light is necessary for its health, and for the normal discharge of its particular function. The eye can adapt itself to varying conditions of light and shadow and of nearness and remoteness in the object seen, but the adaptations are made by the eye itself, and not by the light on the objects revealed by the light.

Similarly, animals living in the Arctic regions are generally provided with thick, non-conducting coverings; the seal has its close, thick-set fur; the whale its layer of blubber. Conversely, in the tropics the hair as a rule is thin and sparse. The cold and heat, however, do not produce an abundance or comparative absence of hair. The amount of hair worn by the Arctic and tropical animals respectively is regulated by forces outside of themselves. Thus the horse has its smooth summer and shaggy winter coat. Land and water birds in the same climate are subject to similar modifications. The water birds, as the duck, goose, swan, &c., have down added to their covering of feathers, which is wholly wanting in the land birds, such as the thrush, partridge, eagle, &c.

Animals even change their colour to suit their surroundings; we have cases of this in the mountain hare and the ptarmigan.

In these instances, as in the others, the changes are effected by the animals under supervision, and not by the surroundings or time of the year. The foregoing remarks apply to many species of animals, and to past and present time. In bygone ages in the cold northern hemisphere there existed a woolly rhinoceros, and a hairy elephant, the mammoth. Animals through prevision have attended to their own clothing and comfort from the very earliest times.

Cold does not necessarily affect the size of an animal; the mastodon, which is the largest quadruped known, was an Arctic animal. It usually does affect the size of the plant, and tends to dwarf it. Some think that animals are also dwarfed by cold, and give as an instance the Shetland pony. In the latter case the scarcity and quality of the food will account for a good deal.

The effect of heat on plants and animals is to encourage growth—tropical vegetation being luxuriant, and the animals of warm countries large. The tropical plants in many cases are fleshy, with hairy coverings and thick skins, and the animals have fine coatings of hair, or no hair at all. Special provisions are made to preserve the moisture of the plant and prevent an undue evaporation of its juices; similar provisions are made for the well-being and comfort of the animal.

One of the most remarkable examples of inherent modification known is that witnessed in the Axolotl. This curious and quaint animal—a native of Mexico—has literally a dual existence. It exists in two forms, namely, as a water-breather and an air-breather, and in each form (and this is the remarkable circumstance) it is capable of propagating and reproducing itself. In the water-breathing form it is known as Axolotl, while in the air-breathing form it is known as Amblystoma.

It is a case of transition from the water to the air. In the Axolotl form it is furnished with six gills, which enable it to breathe the oxygen contained in solution in the water. In the Amblystoma form it is provided with lungs, which enable it to appropriate the oxygen of the air. The change from the one form with gills to the other form with lungs cannot be due to environment or surroundings. The water does not make the gills or the air the lungs. The structural modifications from the water-breathing to the air-breathing type take place in the

animal itself. Perhaps a still better example of inherent modification and transformation is seen in the development of the frog (Plate xciii., Fig. 3, p. 403).

In the tadpole state the frog is provided with gills, and a swimming tail. A time, however, arrives when the gills and tail disappear, and lungs and legs appear. At this critical stage of development small rocks or landing stages projecting above the water must be provided to enable the young frogs to leave the water and to rest and become air-breathers. If this precaution be not taken the young frogs swim about until they are exhausted and drowned. No better instance can be given of prevised structural modifications occurring in an animal apart from its environment and surroundings. The transition from a water to an air-breathing animal, and from a swimming to a walking or leaping form, certainly cannot be attributed either to the water or the air. The structural changes are provided for in the animal itself. They are traceable to the impregnated ovum. This contains the matter and the directive agency which in due time culminate in the adult frog.

It appears to me that it is important to point out the power of development which a frog possesses in virtue of its life, and irrespective of environment or stimuli of any kind, believing, as I do, that all living structures and tissues are provided with similar powers.

In other words, I am of opinion that living organisms and all their tissues can, and do, act apart from external stimuli. That they respond to artificial stimuli is no proof that they cannot act apart from stimuli in virtue of their own inherent powers conferred upon them by vitality or life, the gift of the Creator. The presence of air is certainly not necessary to the rhythmical movements of the chest so well seen in ordinary respiration, and the presence or absence of blood in the several cavities of the heart has nothing to do with the opening and closing rhythmic movements of the heart.

Similar remarks may be made regarding the hollow viscera with sphincters, which exhibit well-marked rhythmic movements at stated intervals apart from stimulation.

The activity of glands is also traceable to inherent movements occurring in the gland structures.

It is absurd to speak of a living thing as a piece of mechanism every part of which has to be set in motion by some extraneous force. To do so is to ignore the life which is alike the distinguishing feature and the prime mover in plants and animals. The fact that a thing lives, and continues to live, affords conclusive proof that it has within itself the power to move in specific directions and to definite ends, apart from stimulation, irritation, and extraneous influences of all kinds. It is the prerogative of life to appropriate, use, and assimilate certain of the elements, and to reject others, so long as it continues in a state of health. It is also free to select and reject the physical forces which inhere in the elements and the tissues formed from them. The life is a master power, and it possesses a master key to imprison, curb, and set free not only the matter but also the force of the universe.

"Purely physical forces, provided with the same kind of materials to work upon, always produce precisely the same general results, and have done so since the foundation of the world. Old sea-beaches very similar to existing ones are in evidence which were probably laid down millions of years ago. Rivers flowed in their beds to the sea then, just as they do now. So, too, chemical combinations and crystallisations went on in all ages exactly as they do to-day with exactly the same results.

"But, when we turn to living organisms, all is changed. The great groups of animals and plants, it is true, have existed in past ages, but nevertheless they have changed in detail again and again, through the epochs of the world's history; and it is only the very latest of the earth's strata which contain organisms identically the same as existing ones. This profound difference between the results of inorganic physical forces as distinct from organic living ones has to be accounted for." . . . "The differences between life and non-life are cumulative. Think of one more, the power of resisting decay and its disintegrating effects." . . . "Numerous chemical changes are prevented in plants and animals as long as they are alive and well. But a green leaf in autumn rapidly turns yellow under the ordinary effect of the air, when its life is enfeebled. Plants rapidly become the prey of numerous parasites, animal and vegetable, when they are in bad health, dying, or dead. But they resisted these when in full vigour. Animal life meets the effect of mechanical strains by increasing muscular and osseous structures. Similarly, plants put on more of the so-called mechanical tissues when subjected to external forces; as may be especially observed in climbing plants.

"When death occurs, all this is changed, and the converse takes place. Hosts of parasites quickly attack the dead being. Chemical changes are rapidly induced by the action of bacteria, which play havoc with the organism, setting up decay and decomposition, which they were utterly unable to do as long as the organism was alive.

"These remarks are enough to show that with our present knowledge it is impossible to see how life could have issued out of the forces of the inorganic world." [1]

[1] Henslow's "The Argument of Adaptation or Natural Theology Reconsidered," pp. 6, 7, &c.

§ 233. Consideration of the Argument for Design.

It has been customary of late years to ignore the argument for design in so far as design necessitates or implies an intelligent Creator or First Cause.

This has been especially the case since Mr. Darwin published his "Origin of Species by Means of Natural Selection." Professor Huxley, Mr. Romanes, and others contended that Mr. Darwin's book had rendered the argument untenable, and practically given it its quietus.

It ought, however, to be explained that Mr. Darwin, in his "Origin of Species," did not concern himself with the argument for design. "His endeavour was to ascertain which of two hypotheses was correct: that of Special Creation, which up to this time had been almost universally accepted, or Evolution. With final causes he had nothing to do; his aim was to investigate, and, so far as possible, account for, the process."

Mr. Darwin in his "Descent of Man" (vol. ii., p. 396) makes his position quite clear. He says: "The birth both of the species and the individual are equally parts of that grand sequence of events which our minds refuse to accept as the result of blind chance. The understanding revolts at such a conclusion, whether or not we are able to believe that every slight variation of structure . . . the dissemination of each seed, and other such events, have all been ordained for some special purpose."

The Duke of Argyll took exception to Mr. Darwin's "Origin of Species by Natural Selection," and wrote his "Reign of Law" as a counterblast to it. "The duke adopted with modifications the views of the teleological school, which saw in all nature the working out of a Purpose and a Mind."

As a matter of fact, Mr. Darwin's "Origin of Species by Means of Natural Selection" left the argument for design pretty much where it was, inasmuch as so-called natural selection may be regarded merely as a process of so-called evolution by which the Creator works and accomplishes His purpose. Indeed the Creator, by conferring upon living matter in its simplest and lowest forms the power of appropriating the elements and building them up by endless elaboration and graduation from a monad to a man, proves Himself to be an infinitely more wonderful Designer than was ever dreamt of by even the most ardent teleologist.

"Looking through the forms of life from the earliest days of this world's history till now, animals have become more and more structurally complicated. As no new structure could come into existence without a corresponding group of directing forces to make it; therefore, as life progressed, so did its forces rise in complexity until man appeared.

"Therefore, until it can be shown that to make a man is not a more complex procedure than to make a piece of granite [so-called], natural selection cannot be equally applied to both kingdoms alike. Until the forces with which protoplasm is endowed can be proved to be strictly parallel with physical forces, it is useless to attempt to bring the organic world into the same category as the inorganic."

Mr. Darwin, with transparent honesty of purpose, great industry, and infinite patience accumulated a mass of interesting detail regarding the variations in plants and animals, and in doing so he recognised life as a prominent factor in the several processes by which variation was produced. The majority of his followers are less discriminating and sagacious. They practically ignore the life, and speak of environment and externalities as *causing* the variation. They, in fact, reduce plants and animals to mere automata, which are galvanised into activity from time to time by the application of artificial stimuli.

Some of those even who oppose Mr. Darwin make similar mistakes. Thus Mr. Henslow says:[1] "One need not pause to establish the axiom that all living beings are subject to variation. This variation is a property of living matter, and is especially stimulated into action by various external influences, as a change of habitat, cultivation, and domesticity." . . . "These differences are due to the direct action of the new surroundings to which the living protoplasm responds." . . . "Now, what stimulates the plant to this extraordinary rapidity? It is nothing but the climate." . . . "The net result is that the plants respond to these external influences, and so can complete their annual course in a given time."

I desire at this point to state my conviction that it is a fundamental error in biology and physiology to regard external stimulation as a necessity in producing movements and modifications of structure in living plants and animals. That such stimulation and irritation can be, and is, in the majority of cases, dispensed with, is abundantly proved by the development of plants and animals in their embryonic stages and by the processes of organic life.

In the case of the seed planted in the ground, there is, heat excepted, no external stimulation. The seed itself supplies the substance, energy, and, in many cases, the moisture required for germination. Potatoes, onions, bulbs, &c., sprout in the spring when the temperature is slightly elevated. Similar remarks may be made of barley in the malting kiln. Succulent fruits of all kinds are to be placed in the same category. Heat is a condition of

[1] Henslow's "The Argument of Adaptation," &c., p. 9.

plant life, and indeed of all life, but seeing it is an essential, and part of life, it cannot be regarded as an irritant or stimulant in the ordinary sense. There are heat and cold limits for plants and animals beyond which life is impossible. In the ova of warm-blooded animals (man, for example), heat and moisture are inherent factors; that is, they are not added, and consequently cannot be regarded as stimuli.

In the case of the fecundated ova of fishes deposited in the bed of a river, the ova themselves supply the substance, moisture, energy, and the little heat which is required for hatching out. The water for the most part is icy cold, so that in this instance extraneous heat cannot be considered. It certainly cannot be regarded as an irritant or external stimulus in the hatching process. The ova of fishes hatch out because of their inherent vitality. Nor should it be forgotten that certain fishes, such as the shark, ray, and blenny, bring forth live young. As the young fish produced from an ovum grows, it gradually devours and assimilates its ovum, which may be likened to a bag of provender. While the assimilating process is going on an alimentary canal is being provided minus a mouth and anus. Just before the provender is exhausted a mouth and anus appear, and the young fish begins to search for food, which it seizes, devours, and digests, the detritus being discharged in due course by the vent. The gradual developments in the fish are traceable, not to irritation or external stimuli, but to a vital power asserting itself according to a preconceived plan and arrangement. Heat and moisture play a part in the development of the fish, but they are both subordinated to the life. The life leads, and is the chief factor in the developing process. It is the life which produces vital activity. The alimentary canal and the other internal and external organs of the adult fish are certainly not produced by any form of irritation or stimulation on the part of the water, or the heat of the water, in which the fish is immersed.

In the case of the chick a precisely similar series of vital changes occur (Fig. 76, p. 386). First there is the gradual development and maturation of the fecundated eggs. The eggs are found in various stages of development in the ovary. The fimbriated extremity of the Fallopian tube is stretched out like an open hand to receive an egg sufficiently advanced. This it transfers to the oviduct. As yet the egg consists of yolk only. It is made to pass down the oviduct by a series of vital vermicular or peristaltic movements, and as it does so it is provided with a coating of albumen (the white of the egg), the chalaziferous membrane, and three layers of shell. In these complicated vital processes irritation or external stimuli can take no part. The whole arrangement is a preconcerted, continuous, natural development, and the different parts of the oviduct add their quotas of membrane, albumen, lime, &c., to the living yolk as it passes downwards according to a fixed plan. The oviduct even causes the gradually maturing egg to rotate during its descent, and hence the beautiful spirals seen at the extremities of the chalaziferous membrane. Throughout the entire process there are abundant proofs of vitality and design apart from irritation or stimulation of any kind.

Heat and moisture take part in the developing process, but the moisture and heat are natural—that is, they are not added or adventitious; they are part and parcel of the life of the parent, and of the developing egg itself. The gradually maturing egg cannot possibly, during its downward transit, act as an irritant, and occasion the production of the albumen, lime, &c., necessary for its completion. Neither can the egg produce the peristaltic movements in the oviduct which finally result in its expulsion. The completed egg is the joint production of the ovary and of the several parts of the oviduct. Whatever powers may be claimed for moisture and heat as external stimuli in developing the seeds of plants, it is obvious that both are factors in the development of the eggs of the warm-blooded birds. Moreover, even when an egg is being hatched out either by the heat of the body of the parent, or by artificial heat, irritation or external stimulation cannot, strictly speaking, be predicated. Heat and air are necessary to the hatching operation, but these are natural concomitants rather than auxiliaries of the hatching process. The heat of the body, as explained, is required to mature the egg. It is also required to hatch it. The air is admitted to the egg in anticipation of the fact that the chick is destined to become an air-breathing animal. The air, however, does not act as an irritant even to the lungs. Similar remarks apply to the eggs of serpents, crocodiles, &c.

As regards the human ovum the case is in no way different (Plate xci., Fig. 3, p. 393, and Plate xcv., p. 407). The ovaries, and the ova they contain, are found even in the female child. When the period of adolescence arrives the ova begin to ripen in rotation. After each monthly period one or more ripe ova swell, burst, and escape from the surface of the ovary. As a rule they are caught by the funnel-shaped, fimbriated extremity of the Fallopian tube and conveyed into the interior of the uterus, where they are impregnated. They are sometimes impregnated in the Fallopian tube, and occasionally on the surface of the ovary, and hence Fallopian and extra-uterine pregnancy.

The seizing of the ova by the Fallopian tube, which is free to move over the surface of the ovary, is one of the most remarkable facts in physiology. The movements of the Fallopian tube cannot possibly be caused by irritation or external stimulation of any kind. They afford a pure example of design and means to an end.

When the ovum has reached the interior of the uterus it is impregnated, and a series of the most wonderful changes in nature is inaugurated. Not one of them, in my opinion, is due to irritation or external stimulation.

The human ovum carries with it into the uterus the substance, moisture, heat, and directive force necessary for its development, and this development, such is the potency of the ovum, can take place within either the uterus, the Fallopian tube, or the abdominal cavity. The ovum is a living entity, which can develop what are virtually rootlets (shaggy chorion and fœtal portion of placenta) (Plate xc., p. 391; Plate xcii., p. 396), with which it temporarily fixes itself to a mucous surface of the mother in either of the situations indicated, and from which it derives sustenance and oxygen so soon as its own substance is absorbed and assimilated. The ovum, as I pointed out in 1872,[1] may be regarded as a parasite which simply places itself against a mucous surface containing blood-vessels, glands, &c., during the period of gestation.

The mucous surface performs the part of a stomach and a lung to the fœtus. When the parturient period arrives, the temporary connection between the fœtus and the parent is terminated, without detriment or hurt either to the child or the mother, by rhythmic movements which occur in the uterus. These rhythmic movements are slow and comparatively painless at first. They increase in frequency and violence as labour proceeds, and are known as the labour pains. In a perfectly natural labour next to no blood is lost. In aboriginal tribes on the trail only an hour or two of repose is allowed to a woman in travail.

The celerity and ease with which aboriginal parturition proceeds is due to the loose temporary connection existing between the mother and child, and to the construction of the placenta or after-birth. The placenta consists of two parts—a maternal and a fœtal part. Both have a similar composition. They consist of a mucous surface and a large number of blood-vessels, glands, and glandular spaces; the blood-vessels being arranged in conical tufts, which fit accurately into each other by a process of inter-digitation (Plate xcv., Fig. 3, p. 407; Figs. 139 to 160 inclusive, p. 480, &c.). If the fingers of the one hand be passed through those of the other a good illustration of the arrangement may be obtained. As the vascular tufts of the mother and fœtus do not open into each other but are simply placed in apposition, it follows that the two may be separated at birth by a simple process of withdrawal—no bleeding being induced. Bleeding, when it occurs, is produced for the most part by abnormal adhesions and the rupture of blood-vessels during parturition. The adhesions and rupture of blood-vessels referred to are largely the result of sedentary habits and other unnatural conditions incident to an artificial state of civilisation.

The fœtal child is thrown off by the uterus at the full time, much in the same way that a leaf is thrown off by a tree in autumn. In both cases due preparation is made for the throwing-off process. Neither is thrown off by chance.

That the child *in utero* during its development does not act as an irritant is proved incontrovertibly by the fact that for the long period of nine months it occasions little or no uneasiness to the mother. If it did act as an irritant it would undoubtedly be extruded long before the period mentioned. Neither does the fœtus produce its own expulsion. The uterus is expressly formed to contain the fœtus for nine months and to extrude it at the end of that period.

That the uterus is made to contain and expel of its own accord is evident from this. The *os uteri* opens voluntarily, so to speak. The gradually dilating *os* is the first stage of parturition. The *os* is not forcibly widened by uterine contractions, as dilatations take place before the contractions set in. Similar remarks may be made of other containing and expelling hollow viscera, such as the heart, stomach, bladder, rectum, &c., all of which are expressly designed to contain and discharge substances at intervals irrespective of irritation or external stimulation.

In the case of the developing human fœtus, moisture and heat are supplied from the outset—man being a warm-blooded animal.

In a human pregnancy moisture and heat do not play the part of extraneous stimuli. Many other examples of fœtal development as apart from irritation or external stimulation may be cited. During the parturient period a whole cycle of important changes are inaugurated and carried out in different parts of the body. The constitution of the mother is profoundly affected by conception. Every part of her body, and even her mind, undergo visible changes.

So far-reaching are the effects that a first conception not only stamps the progeny with the impress of the first sire, but also the after progeny by future sires. A black father transmits colour to the children of a white mother, and also in many cases to the children of the same mother by a subsequent white father. The famous John Hunter first directed attention to this remarkable fact. He put a young English blood-mare to a quagga horse. Her first offspring revealed the characteristic stripes of the quagga in a marked manner. The same mare was subsequently put only to English horses, with the result that the stripes, while they persisted, became more and more faint. This fact is well known to scientific breeders of stock, who are most careful to put their horses,

[1] *Edinburgh Medical Journal.*

cattle, sheep, dogs, &c., only to the best sires for the first conception. The physical as well as the intellectual properties of the first and succeeding sires are transmitted to the offspring, and hence the common phrase, hereditary transmission and descent. How it happens that the fusion of two jelly-looking specks of living protoplasm after coitus should produce such extraordinary results cannot at present be explained. The fact that the changes occur invests life with quite a superior dignity. The potentiality of the reproductive process is simply marvellous. It furnishes one of the most powerful arguments for design, inasmuch as every living thing produces only its own kind, and the impress of the parents is indelibly stamped on the progeny. The offspring in due time passes on the peculiarities in endless succession to future generations. In the transmission of original peculiarities and of acquired properties and qualities—physical and intellectual—is to be found the key to the so-called instincts of animals and the god-like intellect of modern man.

Animals and primitive man, there can be little doubt, originally acquired their knowledge by experience. As I believe experience is cumulative in the individual and in the race, and, within limits, transmissible, it follows that all knowledge in animals and in man is obtained by the operation of a law of cumulation and transmission which has been at work for countless ages, and which is still in force.

The effects of the law are seen in those wonderful previsions and adaptations, in virtue of which the lower animals work out their own destinies, by which they seek and obtain daily food, build nests, store food for the winter, follow the seasons, and, in the case of birds, take long migratory journeys, which are only to be explained by an ever-extending and transmissible experience.

The remarks here made apply not only to the adult or perfected individual, but also, up to a point, to the incomplete or developing individual. Each step of development is characterised by the exercise of certain powers which ensure growth and protection. This is seen in the development of insects, where the individual eats at one time ravenously (caterpillar stage), and at another provides itself with a house (cocoon), in which it sleeps in a chrysalis or semi-torpid state, awaking at the proper time for hatching out. The food of developing insects is always at hand, the parent taking care to lay her eggs either in, or on, the food, or providing it independently.

The nest of the ant, bee, wasp, and bird, the web of the spider, the house of the trap-door spider, the burrows of rabbits, are all examples of acquired or transmitted experience. The art of nest-building is seen even now in its various stages—some birds making no nests, others very rudimentary ones, while others are very elaborate. The same may be said of bees and ants. There are solitary bees and ants which build comparatively very simple nests. In the case of migratory birds some take comparatively short flights—others inordinately long ones.

The operation of the law referred to explains the so-called instinctive and rational acts of the animal kingdom as a whole. If the instinctive and rational acts referred to be not so explained, then there is no halting-place; they must be referred directly to Divine interposition.

It is now all but certain, from recent microscopic, physiological, and pathological researches, that memory, like the other attributes of mind, has a molecular origin and basis. If it be admitted that the molecules which are transmitted from parent to offspring contain the elements of experience and memory, everything is satisfactorily accounted for. The molecules which represent memory, there is reason to believe, may be trained, educated, and improved much in the same way as the sarcous elements of muscles. Like other molecules, they act in groups at longer or shorter intervals, an arrangement which explains the doctrine known as the "association of ideas," according to which one idea or thought recalls another after a certain interval and in a circuitous manner. The molecules of the nervous system, in which the accumulated knowledge of ages is stored, being vital, mobile, and transmissible, it follows that the increase of knowledge in animals and in man is largely a question of breeding and training, and the outcome of an ever-increasing experience.

As all the parts of living individuals (plants and animals) are in a state of constant flux—new matter being constantly added and effete matter removed—the question naturally arises, How can stability be secured in the midst of instability? The reply is, that as there is an identity of the species and the individual, so there is an identity of the parts, the cells, and the molecules forming the species and the individual. Indeed it is the identity of the molecules, cells, and parts, which secures the identity of the individual and the species. The molecules, cells, and parts of each organism have the power of hereditary transmission. If the molecules and cells, and the parts formed by them, degenerate and die, they nevertheless propagate themselves before doing so. Heredity, transmission, and descent are essentially matters of molecules and cells. They provide the materials for everything that lives.

The changes by which the foregoing extraordinary results are obtained are vital and molecular in their nature. They are not the result of irritation or external stimulation. On the contrary, they are the first-fruits of life asserting itself to the exclusion of every outside influence.

That the body of the mother is influenced in all its parts and particles by conception, that the thing conceived

reacts on the mother, and that the developing offspring and the mother work together to a given end, each revealing the most prominent traces of design and adaptation, is shown by the following facts :—

(*a*) During the period of gestation, particularly towards the full time, the mammæ increase in volume, and milk is produced, so that the infant, the moment it is born, may be fed and nourished. It occasionally happens that in unhealthy, badly grown mothers no milk is produced ; this is, however, an altogether abnormal state of things.

(*b*) The fœtus *in utero* breathes by the aid of the placenta ; nevertheless nature, in view of the fact that man is an air-breather, gradually provides the fœtus with a pair of lungs which enable it to inhale atmospheric air the instant it is ushered into the outer world.

The lungs of a child assuredly are not produced by irritation or external stimulation. As a matter of fact the lungs are gradually evolved *in utero* just as the limbs are, in anticipation of functions to be subsequently discharged.

To say that the mammæ sympathise with the uterus during pregnancy explains nothing. The mammæ exist in an imperfect form in the human female at birth, they become more perfect as puberty advances, and attain maturity at the parturient period. The development of the mammæ affords a most palpable example of pre-arrangement and design.

The so-called vegetative processes of the body are analogous to those of development and growth, as above explained. They are, each and all, essentially vital, independent processes, and are neither inaugurated nor controlled by irritation and external stimulation.

The several gland structures produce their secretions and excretions with unerring regularity in a state of health.

The digestive juices are poured out upon nutrient food when it reaches the alimentary canal. The flow is withheld if the substance swallowed be not food.

In the case of Alexis St. Martin, the Canadian boatman, who had the front of his stomach removed by a gunshot wound, a piece of cooked beef-steak introduced directly into the stomach produced a copious flow of clear gastric juice ; whereas a metal catheter similarly introduced provoked no flow of gastric juice whatever. The stomach distinguished between the two. In the case of the beef-steak the stomach had to discharge a function, and it found itself equal to its work. In the case of the catheter the stomach had no duty to perform apart from extrusion, which it actually attempted. The beef-steak and the catheter were both extraneous substances, and should have acted as irritants and external stimuli and produced like results, which they did not. The insectivorous plants act in a precisely similar manner. If fine particles of chopped beef be dropped upon the leaf of the common sundew (*Drosera rotundifolia*) (Figs. 28, 29, and 30, pp. 127, 128, and 129), its highly sensitive hairs at once move in such a way as to pin down the edible particles to the surface of the leaf. This done, the glands of the leaf pour out a digestive fluid (Fig. 30, p. 129) in all respects analogous to gastric juice. If the particles dropped on the leaf be not edible and nutritious no digestive fluid is exuded. The sundew, like the stomach, exercises a power of discrimination. The behaviour of this remarkable plant (*Drosera rotundifolia*) is very extraordinary. Repeated experiments show that its sensitive hairs not only fold over and secure real food, whether chopped meat, fly, beetle, &c., but remain folded until the food is actually digested, when they gradually straighten themselves (Fig. 29, p. 128). If by any chance the sensitive hairs fold upon non-edible particles they at once begin to unfold—no digestive fluid being poured out. Here we have another example of preconcerted movement and design.

The insectivorous plants belong to several different families. They form connecting links of a kind between plants and animals in so far as they feed like ordinary plants by their roots, while they seize and devour small flies, beetles, and other living things by their leaves. The leaves of the insectivorous plants are provided with special glands for the preparation of a solvent digestive juice, and there are not a few plants the leaves of which reveal a similar formation in a less developed form. The capacity of the leaves of plants to assimilate animal juices need occasion no surprise when it is remembered that the leaves and roots of a plant are essentially identical structures, and can perform similar functions. The roots of plants greedily devour and assimilate the juices of dead animals. The leaves of several plants perform similar functions.

The several glands in the animal economy prepare their secretions from the same blood, but the secretions of the body vary greatly in ultimate composition.

The glands, like the stomach, are living structures, and exercise a selective power. The blood cannot act as an irritant and cause the one gland to produce saliva, another gastric juice, another pancreatic juice, &c.

Similarly with the excretory organs. The kidneys and the sweat glands draw their peculiar excretions from the same blood ; but, as is well known, the urine and the perspiration differ considerably in chemical composition.

In the synthetic and analytic processes of the body the several organs and tissues act of their own accord. Their independent vital action is necessary to the building up of the body by selecting and incorporating whatever is useful and good, whether food, drink, or air, and by rejecting and eliminating whatever is useless and bad.

If the alimentary canal and liver become diseased, healthy digestion, assimilation, and nourishment become impossible. If the kidneys and skin cease to act, the system becomes poisoned, and death, sooner or later, supervenes. The animal economy is to be regarded as a whole, and so long as it lives and is healthy, its organs and tissues perform in one sense a vital and independent rôle—all the organs and tissues, however, acting together harmoniously to a given end.

As the parts are essential to the whole, so the whole can only act normally when each part duly discharges its peculiar function. The due performance of the functions of the body is referable in every case to inherent vital action apart from irritation and external stimulation. The body and the parts composing it perform their allotted task according to a fixed plan. There is nothing haphazard in the arrangements.

When I speak of each part duly performing its function and acting, within limits, independently, I of course speak of a conditioned and subordinated independence, for every physiologist knows that the body, in one sense, is a mass of action and reaction. The food nourishes the blood—the blood all the tissues: the lymphatics mop up the overflow of the blood, &c.

Digestion cannot go on without food—absorption, assimilation, and nutrition depend on digestion; the digested food enriches the blood—the blood feeds the nerves, muscles, glands, &c.; the brain performs the intellectual functions of the body—the muscles the ordinary work of the body.

This is true of every part of the body—brain, nerve, muscle, bone, glands, &c., &c. A complex organism would be an impossibility unless each organ acted in unison with every other organ, and each faithfully performed a special function. If irritation and external stimulation, which at best are casual in their operation, were permitted to interfere or control the final issue, it would be a case of confusion worse confounded. Differentiation of labour is another phrase for design successfully carried out.

The tissue which above all others in the body is believed to be under the influence of irritation and artificial stimulation is muscle; but, as has been already shown, the muscles of organic life, such as the heart, alimentary canal, bladder, uterus, &c., act independently. If it were not so the higher animals could not possibly exist. It has further been shown that even the voluntary muscles after long training come to act automatically, and apart from stimulation—if, indeed, the action of the nervous system on muscle, as seen in volitions and so-called reflex phenomena, can strictly speaking be regarded as stimulation. Nerves and muscles as vital tissue can certainly act apart from stimulation.

The brain and the nervous system educate the voluntary muscles to perform certain movements, and these movements can be made when the mind is fully occupied, and even during sleep.

I am aware of the labyrinth of reflex action which modern physiology assumes to be necessary to keep a complex organism at work, but the organs, structures, and tissues to which I have directed attention are all, within limits, self-acting, and the nervous system co-ordinates rather than causes the performance of the multitudinous functions of the higher animals, and especially man.

There is, moreover, a consideration of the highest importance to which attention must now be directed, namely, that in the higher animals with well-defined nervous systems the organism in a state of health works as a whole and not in parts. It follows that a compound animal with a complex nervous system acts directly through its nervous, muscular, and other systems, and that any one system cannot be isolated and regarded as playing the part of a special stimulus to the others. This is particularly true of the nervous and muscular systems, which are so inextricably and intimately blended that the one cannot be considered apart from the other in the living being, and under normal conditions. There is, I am well aware, an extensive literature on muscular action under artificial stimulations, but when muscles are tortured into activity and, in many cases, isolated and detached from their natural connections and deprived, or partly deprived, of their nerve supply, the results are, in every instance, unreliable and unsatisfactory. In the modern mechanical physiology cause and effect are not unfrequently confounded, and a bewildering labyrinth of error introduced. It is now evident that the whole subject of nerve and muscular physiology must be reconsidered from the vital and normal point of view, as contradistinguished from the mechanical and abnormal point of view. It is self-evident that if one of the simplest lower animal forms can, and does, work as a whole without a nervous system, it is equally competent for one of the higher complex animals to work as a whole with a nervous system. Nothing is gained, but everything lost, by regarding the compound animal as a patchwork or a collection of heterogeneous opposing elements.

The attributing to mere externalities changes which undoubtedly occur in the living organisms themselves is alike misleading and confusing. It is confounding cause and effect. Living things adapt themselves to their surroundings, but this is quite another thing from saying that the surroundings necessitate or produce the adaptations.

The following embodies Mr. Henslow's views regarding protoplasm and cognate subjects.[1] Speaking of proto-

[1] "The Argument of Adaptation or Natural Theology Reconsidered," by Rev. George Henslow, M.A., F.L.S., F.G.S., &c., p. 14, &c.

plasm, he says : " Think of its many endowments. One is called sensitiveness or irritability, by means of which it can respond to external influences. One of its several functions is to build up tissues which shape themselves into structures or organs useful to the being. They are not, however, bound to be always and absolutely of the same pattern in every individual of the same kind, as if turned out of a mould, or like the angular dimensions of crystals. There is a plasticity in its powers of manufacture." . . . " When animals and plants are made to grow *under the stimulus of various surroundings* and climates, the offspring may grow up to maturity and exhibit certain marked differences from their parents." . . . " Similarly for variations. We cannot account for them. We see them arise every day and everywhere ; but *why* the seed of a wild parsnip, when sown in a rich garden soil, in a few generations produces the root of the familiar vegetable which does not grow precisely like the wild wiry root everywhere else, is unanswerable. How it is that all the numerous varieties of domesticated pigeons have arisen from the wild rock pigeon—as is known to be the case—is a mystery we cannot explain. We can only say they are the results of the responsiveness of protoplasm to the external conditions of domestication." . . . " It is of course due to this marvellous power that nature has provided us with innumerable garden plants and breeds of cattle. In this power of responsiveness and adaptation with variation, we see a new feature quite unknown in the inorganic world."

It should be here pointed out that while every one admits that living things modify themselves slightly under altered conditions, it does not follow that they alter themselves beyond recognition. The parsnip remains a parsnip, and the pigeon a pigeon. Nay more, if the cultivated parsnip and pigeon be left to themselves, or permitted to breed back, they return to the wild stock from which they sprang.

The same may be said even of educated man. The externalities or environment, the new conditions, do not make a plant or an animal what it is. Plants and animals owe their peculiarities and properties not to externalities but to their vitality or life and original endowments. The changes effected in plants and animals come from within and not from without. This remark applies not only to plants and animals as a whole but also to all their tissues.

This follows because the directive agency or power which produces all the changes of shape and structure in living organisms inheres in the living things themselves. That this is so is proved by a reference to living protoplasm as it occurs in the spore, germ, seed, and egg.

Huxley regarded protoplasm as " the physical basis of life." He further regarded protoplasm as a simple rudimentary substance, which is homogeneous and identical in all its parts and particles.

I combated this view so far back as 1872,[1] and maintained that protoplasm is not a simple but a highly complex substance, and contains in itself, in a potential but invisible form, all the properties and many of the elements which characterise the future individual, whether plant or animal.

It is true that the microscope fails to differentiate protoplasm, and that chemistry and physics are next to helpless in discovering and defining its true properties ; but the fact that from spores, germs, seeds, and eggs, which are apparently identical, wholly different plants and animals are produced proves, beyond doubt, that the germinating material is radically different, both as regards substance and function, from the first.

That the difference is initial in its nature, and consists largely of a directive force or agency, is evident from this, that the several kinds of plants and animals are developed under strictly similar conditions of air, moisture, heat, &c. In other words, the environments in either case are strictly analogous.

All plants and all animals are descended from parents, which they greatly resemble in original form and constitution, and both plants and animals transmit hereditary tendencies which can never be ignored. In hereditary transmission we find an explanation of the so-called instincts of plants and animals. Experiences acquired during one generation are passed on to other and succeeding generations, with the result that plants and animals are, or may be, improved from the physical side and from the mental side when a nervous system exists.

Those who hold different views have to account for the outstanding differences to be met with in the several orders of plants and animals ; they have to show how each particular spore, germ, seed, and egg produce only their own particular kind.

They have to explain, for example, how an apple cannot be produced from the seed of a gooseberry, nor an elephant from the ovum of a mouse.

My contention is that forms so dissimilar cannot possibly be produced from protoplasm, which is structurally homogeneous and identical in all its parts and particles.

Neither can they be produced by any merely physical force. They demand for their existence a multiple, highly complex, potential, plastic material, and a marvellous directive agency which vitality or life alone can supply.

[1] Introductory Lecture "On the Relation of Plants and Animals, &c." (*Lancet*, 15th November, 1872.)

The properties of the protoplasm must be co-extensive with the capacities of the organisms and the tissues and structures produced by it. The living protoplasm must inaugurate the physical and other changes which result in the formation of tissues, organs, and organisms. It must not only inaugurate these changes; it must continue them until the adolescent or adult stage is reached. Nay more, it must carry them on so long as life lasts. Protoplasm inaugurates and carries on life. When the protoplasm of the plant or animal dies, the individual itself ceases to exist.

It is to living protoplasm that plants and animals originally owe their existence, and all modifications of their structures throughout the ages are traceable to the same source.

Living plants and animals, even the most rudimentary, cannot be manufactured in the laboratory of either the chemist or physicist. They can only be produced from the elements in the great laboratory of nature by living protoplasm under supervision, the protoplasm having been transmitted from parents or pre-existing spores, germs, seeds, or eggs. To this there is no exception. There is no such thing as spontaneous generation. There are two leading theories of creation, the one consisting of a single act, the other of several acts. The single creative act embraces the whole creative process, and is not confined in its scope. The multiple creative acts are arranged piecemeal fashion, or as tiers are arranged, the one above the other; the one tier producing the material for another and successive tier according to pre-arrangement and design.

The difficulties experienced in dealing with living protoplasm are due—

1. To the insufficiency of the microscope in dealing with ultimate matter; and

2. To the very small quantities in which protoplasm exists in spores, germs, seeds, and eggs, which largely precludes the possibility of reliable chemical analysis.

So far as recent modern analysis goes protoplasm is an extraordinarily complex substance with apparently infinite possibilities. So much is this the case that it may be regarded in the light of a universal substance with a universal function. According to Henslow:[1] "It contains potentially all the peculiarities, properties, capacities, and, in the case of higher animals, mental characteristics of the being." And these can be transmitted to the offspring—the offspring, as a consequence, always more or less closely resembling the parent.

It is not contended that the protoplasm found in spores, germs, seeds, and eggs contains all the elements found in mature plants and animals. The only protoplasm found is that required under the influence of life to inaugurate the first series of developments, and each series appropriates new elements according to the requirements of the individual, whether plant or animal.

The materials from which, and the powers by which, plants and animals are formed are cumulative until the individual is developed.

All plants and all animals derive their component parts from the inorganic kingdom. They are built up from the elements around them synthetically; at death the elements are liberated or set free by analytic processes. During life the elements freely circulate through plants and animals; the living organisms and the tissues composing them selecting certain elements and compounds and rejecting others. The prerogative of life is to select and reject at pleasure and according to existing requirements.

The elements which enter into the composition of plants and animals carry into both the physical forces which inhere in these elements as such, but the vital forces dominate the physical forces as they dominate inorganic matter. They alternately appropriate and reject the physical forces; a plant in growing upwards counteracts the force of gravitation, but it avails itself of other forces, such as osmosis, capillarity, cohesion, &c.

A plant can reduce and incorporate inorganic matter by a vital chemistry directly; and the animal in turn appropriates and assimilates the organic matter of the plant, or of the animal fed upon the plants. The plant precedes the animal, but there is reciprocity between them when both are formed. The dead plant affords nourishment to the living animal, and the dead animal in turn provides nourishment for the living plant. The animal during respiration takes in oxygen and gives off carbonic acid and other matters; the plant, on the other hand, takes in carbonic acid and gives off oxygen.

Inorganic matter and physical force always act in the same way: organic matter and vital force, on the contrary, are a law unto themselves, and never act precisely in the same manner in any two cases. There are infinitesimal differences, which admit of modification, but which are not necessarily destructive.

Physical force as we know it produces heat, light, electricity, &c., and is finally dissipated; vital force builds up plants and animals which reproduce themselves in endless succession.

The material and physical force stored up in plants by the aid of the sun in the shape of coal can be liberated after long ages and made to do physical work. There are endless reactions between the organic and the inorganic kingdoms.

[1] "The Argument of Adaptation or Natural Theology Reconsidered," p. 52.

The views of those who do not believe in life as a separate entity, who discredit and deny the existence of vital force, and who pin their faith exclusively to matter and physical force, are thus stated by Beale :[1]

"The living and the non-living are one.

"All movements in living things are physical, and are due to chemical change.

"Life is made up of physical and chemical action.

"Vital mechanics—vital chemistry.

"Man is a machine, and all his actions are mechanical.

"The sun is the source of life.

"Suns resolve themselves into living things.

"Living things are built by the sun.

"The sun forms hearts and brains and tissues and organs.

"The living comes direct from the non-living.

"Plants are nearer to the non-living than animals.

"All life came from matter, is due to the ordinary properties of matter, and obeys mechanical laws.

"Living 'protoplasm' is a proteid, and obeys ordinary chemical laws.

"The 'growth' of living and lifeless takes place in the same way.

"Aggregation is a form of 'growth.'

"Crystals *grow*."

Beale makes the following distinctions between living and non-living things :[2] "One most important characteristic of all life is *growth*—the growth known *only in connection with life.* It has been said, and it is widely believed, that growth also occurs in non-living matter, and that the process I hold to be vital only, is but a form of aggregation of material particles. This doctrine I can only meet with a direct negative. The formation and increase of every tissue—every structure of every living organism that I have been able to study—does not take place according to any such process, and is absolutely dependent upon purely vital phenomena in each case. The facts of microscopical investigations extending over a long period have convinced me that there is no 'community of nature' between *growth* as it occurs in everything that lives, and *inorganic growth*, as has long been taught by Mr. Herbert Spencer. . . . I venture to maintain that living and non-living matter belong to *absolutely different categories ;* and that there is no analogy whatever between aggregation and accretion, and *growth* as it occurs in all living. The statements in the first paragraph of the chapter on Growth seem to me to be contrary to evidence, opposed to reason, and incompatible with *broad facts of living nature*, as well as with the results of minute investigation.

"'Crystals grow' (Herbert Spencer). If the solution containing the crystallisable substance passed through the *outer part of the crystal* and crystallised within : *if* the new matter somehow reached the central part of the crystal : *if* the outer layers of the crystal consisted of the matter *first* deposited from the solution : *if* the crystal increased in size by deposition *from within* so that the superficial layers were pushed outwards as the crystals increased in dimensions—in short, *if* the deposition of crystallisable matter from its solution occurred in a direction *the very opposite of that* in which it does occur—the existence of some slight analogy between *growth* as it takes place in the 'cell' of a living organism and the so-called *growth* of the crystal might be conjecturally assumed.

"*If* the fungus-like accumulation of 'carbon' upon the wick of an unsnuffed candle was increased by the last-formed portion of the carbon being somehow carried inwards through the outer layer towards the wick, so as to push out the layer first deposited, it might be said that the order of deposition was in the same direction and situation as occurs in the so-called cell-wall, as, in certain cases, it is thickened.

"*If* the deposition of sediment occurred beneath the stratum just deposited instead of *upon* it, the process might be roughly compared with *living growth. If* 'celestial bodies' increased by deposition *from within*, and the last matter added reached the nucleus or central part, their increase might by some authorities be compared with growth 'in its widest acceptation' (Herbert Spencer).

"*Evolution* surely is applicable to vital phenomena only, aggregation to non-living matter only—evolution *from* already existing centres—movement *from* a spot, movement *towards* a spot—centrifugal, centripetal—away from, towards—from, to. If this be so, aggregation and evolution are *opposed*, and cannot involve the same particles of matter ; and the genesis of bodies 'celestial' can hardly proceed like the 'genesis' of living organisms terrestrial. Aggregation of lifeless particles seems, therefore, to belong to a category far away from that to which living growth belongs. *Aggregation* is absolutely different in essential nature from *growth*, and the two processes are

[1] "Vitality : An Appeal, an Apology, and a Challenge," by Lionel S. Beale, F.R.C.P., F.R.S., &c., p. 9.

[2] "Vitality : Replies to some Objections and a further Appeal," reprinted (with additions) from the *Lancet*, 1899, p. 9.

absolutely opposed, and cannot possibly affect the same particles at the same time. *Evolution must be restricted to the living world*, or it can have no definite meaning.

"So far, then, I feel compelled to maintain that between life and non-life the difference is *absolute*, whether we consider the life of the lowest fungi growing and multiplying in teeming millions at this moment upon every dead moist leaf, or the life of the so-called 'cells' of the wonderful grey matter of our own cerebral convolutions."

Considerable confusion, it will be perceived, exists as to the precise nature of living and non-living matter, and the formation of crystals and the lowest organisms.

There are cycles of change between plants and animals and between both and the inorganic kingdom.

"M. Dumas made the beautiful generalisation, that an animal should be regarded, in a chemical point of view, as an apparatus of combustion, which incessantly returns to the atmosphere carbonaceous matters in the shape of carbonic acid, hydrogen as a constituent of water, and nitrogen in the form of ammonium oxide. In short, from the animal kingdom as a whole, there is constantly given off carbonic acid, watery vapour, and nitrogen. Vegetables, on the other hand, absorb and fix these substances, retaining the carbon and hydrogen, and setting free the oxygen. They also abstract nitrogen directly from the air, or indirectly from ammonium oxide, or nitric acid. Vegetables, for the most part, form organic matter under the influence of solar light. They pass ready formed as food into the bodies of animals, which, during their life, or after their death, restore them to the atmosphere from which they were originally derived. Thus the animal kingdom is an apparatus of combustion, the vegetable kingdom an apparatus of reduction; the one produces the elements which the other consumes; so that, in the language of Dumas, they are the 'offspring of the air.' They come from the atmosphere, and return to it again.

"The various mineral matters which enter into the constitution of living beings, exhibit the same dependence which animals have upon vegetables, and these, again, upon inorganic matter. They simply pass through living beings, as it were, to serve certain important purposes in the scheme of life. Let us take lime and sulphur as examples. Rain water, loaded with the carbonic acid of the air, falls upon calcareous hills, and carbonate of lime, in a state of solution, enters rivers, and is by them carried to the ocean, where it is seized upon by millions of animals, and converted into their external skeletons or shells. The water of rivers and springs also is absorbed by plants, and drunk by animals; and so lime enters into their substance, and is converted into various salts of that base, such as oxalates, tartrates, phosphates, &c. Phosphate of lime is the principal element of the bones, besides entering more or less into the constitution of the other tissues of the superior animals, which are continually excreting as well as assimilating it. Lastly, on their death, the lime is dispersed in various ways; even the bones crumble to pieces; and so the mineral returns to the soil, from whence it came. Sulphur passes from one region to another, in a similar manner—from the sea, which contains sulphur in large quantities, to the atmosphere, thence to the soil, and thence to plants and animals, from whence, again, it returns to the bosom of the ocean.

"These incessant exchanges between the soil or atmosphere, plants, and animals, constitute the theory known as 'the chemical balance of organic nature.'"[1]

The intimate relation existing between plants and animals and between the organic and inorganic kingdoms make the former amenable, within limits, to the latter, and hence all plants and all animals are affected by climate, by day and night, by the seasons, and by cold and heat.

Darwin was of opinion that plants and animals in a domestic state were being constantly varied and improved by cultivation and breeding, in which man exercised an artificial selection; and being aware that plants and animals varied also in the wild state, he conceived the idea that there must of necessity be a selection in nature (natural selection), and that in this only the fittest would survive. It is important to point out here that while artificial selection as practised by man is an accomplished fact, there is no sufficient proof that anything corresponding to natural selection exists. It is not logically permissible to bracket hypothesis and fact, and place them in the same category, as of equal value.

The variation is much greater in the cultivated than in the wild state; hence Darwin's terms, indefinite and definite variation.

The following differences are to be noted :—

Under cultivation man selects and protects his plants and animals from competition. In nature there is no such protection. According to Darwin, plants and animals are in a state of perpetual warfare, each fiercely contending for the food of the other. There is, however (and this is the kernel of the whole matter) no proof that plants and animals do contend and struggle in the race of life in the manner indicated. There is no proof that either the organisms as a whole, or the parts forming them, are in any sense imperfect, and require amending by natural selection or otherwise. A contrary belief is steadily gaining ground, and there are many at the present day

[1] "Text-book of Physiology," by John Hughes Bennett, M.D., F.R.S.E. Edinburgh. 1872, pp. 6 and 7.

"who lay little or no stress at all on natural selection, as a necessary aid in the process of establishing varieties of plants and animals" (Henslow, p. 3).

There is one unanswerable objection to Darwin's theory. He requires for the changes which result in the origin of species *unlimited time*. If, however, unlimited time be required to prove his argument, it is withdrawn from the province of human reason. It is impossible for the finite mind to argue about a thing practically infinite. The question of time alone makes the origin of species by natural selection a hypothesis pure and simple, and much injury has been done to the memory of Darwin by his followers regarding his theoretical statements, upon a most important question, as facts. What he stated tentatively and with great modesty as probable, has been dogmatically asserted by his followers to be true. The sagacious master has been forced into a false position by rash pupils.

The experience gained by members of the animal kingdom is not lost, any more than it is in man. Indeed, in the primitive ages, the difference between man and animals was not so marked as in the present day. Time was when savage man was very little removed from the highest of the lower animals. He had to work wearily upward through the stone age, the flint age, the bronze age, and the iron age to his present exalted position. It is only during the historic period, and more especially since the introduction of writing and printing, that he has made enormous strides in civilisation. Until writing and printing were introduced, all knowledge and history were handed down by oral tradition, in which memory played the leading part. The poems of Homer and other great epics were handed down orally. The experiences and knowledge of existing man are now recorded, and in a way in which the experiences and knowledge of animals cannot be recorded. But it is well to bear in mind that at the outset it was not so, and that in the early days men and animals had more or less equal facilities for acquiring, storing, and transmitting knowledge. As a matter of fact, reasoning and knowledge are not peculiar to, or the prerogatives of, man. Animals have their hereditary guides in a cumulative memory, much in the same way that modern man finds his *tour de force* in his library.

That the acts of many of the lower animals are reasoned and eminently reasonable will appear from even a cursory examination.

Spiders weave a web which is a veritable net and trap for securing live animals for food. The spider, having set his snare, lies in wait, and if a hapless fly, beetle, or bee is caught, and by its struggles is breaking the web and is likely to escape, the spider darts from his hiding-place and throws one or more guy ropes, or another portion of the net, round him. This I have myself seen. The spider has his larder, and stores up food for the winter.

The trap-door spiders make a nest for protection, which they cover with a hinged lid, and which they open and close at pleasure. Some of them provide what is virtually a back door for additional protection and escape. These I have seen on the Italian Riviera.

The ants build a nest which is comparable to a complex human habitation. The nest is divided into endless compartments, and the community of ants is under discipline and control. The ants have bands of ordinary workers. They have also their warriors and slaves. They even capture and keep in captivity large numbers of the aphis, an insect which supplies them with a sweet secretion. On a warm sunny day the ants afford an interesting study. These I have frequently watched in the Engadine. On one occasion I observed an earthworm the size of a little finger lying on the footpath ; a large number of ants were rushing about in an excited state in its immediate vicinity. They presently greatly increased in number, and at a concerted signal they arranged themselves on either side of the worm, which they gradually carried off to their nest. I saw the same thing happen to a full-grown butterfly. The way in which the ants rush about with large loads of pine needles and miscellaneous substances is truly astonishing, but each load is duly taken home and employed in some construction or other. All the labour is accounted for. The ants provide a home and provender for the winter ; their industry is proverbial. The bee is not much, if any, behind the ant. It collects wax and builds a nest ; it also gathers honey in the summer, which it stores and eats in the winter. The beehive is duly ordered. There is the queen bee (which lays the eggs), the males or drones (which do no work), and the working bees or neuters. When the queen bee is impregnated the drones are killed off. Generally two or three queen bees are reared, to guard against accident. They are much larger than ordinary bees, and are manufactured, so to speak, by a special kind of food. When the queen bees are fully developed a selection is made and the others destroyed. The queen bee elect takes her hymeneal flight and all the young bees hive off with her. She founds a new colony. When the combs are made she lays an egg in each cell or certain of them, and there is no more interesting sight than to see the queen bee so engaged. She carries on her work of egg-laying most sedulously and systematically. When exhausted by the process she pauses, and six attendant bees wait upon her and feed her with honey extruded from their proboscis ; of this she partakes daintily. This I have seen in a glass hive at Yester, the residence of the Marquis of Tweeddale. The combs not filled with young are filled with honey for the food of the hive. The bee goes great distances (miles in some cases) to collect honey. However devious its out-going journey, its home journey is always in a

straight line—the so-called bee line. By what power does the bee guide itself ? Bees protect their nest against all comers, and when excited or angered their temperature rises. They are then dangerous. On one occasion a small nephew of mine poked one of the beehives in the garden with a long, stiff wand. He was instantly attacked, and stung in the face and neck in eight or ten places. I had the utmost difficulty in driving the attacking bees off. It occasionally happens, when bees are being taken to the heather in Scotland, an accident occurs to the horse and cart conveying them, whereby one of the hives is upset ; in such cases the horse is not unfrequently stung to death.

The wasps also build nests. They are sometimes found in trees and sometimes in holes in the ground. They also have a political economy of their own. They make combs, lay eggs, and provide for their young in due season. The way in which the latter function is discharged is astonishing. The wasps may be seen in sunny porches, dwelling-houses, and hot-houses, hunting and capturing flies, which they deliberately deprive of their wings and legs and carry off ; sometimes a wasp will attack and conquer a large bluebottle, and treat him in the way indicated. The wasps pursue their cruel tactics also in the open, and it is no uncommon circumstance to see a large wasp fighting and killing a vigorous bluebottle in the air. While the wasps live largely on the sweet, succulent juices of plants and fruits, they do not occasionally object to a little animal food. Wasps can be readily irritated. I have flicked one with a towel in a room until he darted about furiously and raised the pitch of his hum or drone.

I will never forget, when a boy, attacking a strong wasp's nest located in a grassy bank, with a bunch of broom. I belaboured the golden stream of wasps entering and leaving the nest until exhausted, when I innocently thought to retire unmolested. I had reckoned without my host. I was pursued by several wasps, and by one persistently, which I could not drive away. I took to flight, but the wasp was more fleet than I. Whenever I stopped it made for my eyes. When I reached the edge of the field and could get no further, it stung me in the corner of the left eye. I instantly squelched it and had my revenge, but the sting rendered me blind for several days after.

On one occasion in the spring I paid a visit to the famous Zoological Garden at Hamburg. I examined a small glass-house containing large and small lizards, tree frogs, and water snakes, and was astonished to find a large number of small lizard tails lying about. I was puzzled to account for the phenomenon. I was aware that lizards could cast their tails, but where were the bodies to which the tails belonged ? I had not long to wait for an explanation. While I watched, one of the large lizards, resplendent in green and gold, seized one of the smaller lizards at the root of the tail and off flew the appendage. The large lizard then worked round and seized the smaller lizard by the head, which he promptly swallowed. The small lizard—minus its tail—exactly filled the alimentary canal of the larger lizard to the root of the gullet up at the mouth. If the tail had not been amputated it must have projected from the mouth. Query, had the larger lizard reasoned the subject out ?

Poisonous snakes sting their prey, and wait for the poison to overpower or kill their victim before they swallow it.

Non-poisonous snakes seize, crush, and partly kill the animal before swallowing it. I have watched both operations at the Zoological Gardens, London. The poisonous and non-poisonous snakes know their own powers.

Some fishes stalk flies on sedges, and drive them into the water by projecting a drop of water from the mouth.

The fishing frog conceals his body and exhibits and waves the tassel of his fishing-rod as a bait. The fishes so attracted are subsequently devoured.

The blenny and stickleback build nests in the water, and the males herd and guard their young. Fish can be trained to come to the sound of a bell for food. Fish in unpopulated districts are unwary, and easily caught with artificial baits. In populous districts, where fishing is common, and they get frequently pricked by the hook, they are exceedingly difficult to take. This is especially true of brown trout.

Similar remarks may be made of all animals in a state of nature. At first they are tame and readily approached ; after being hunted, captured, or killed, they become exceedingly shy and wild. My friend Sir John Kirk informed me that, in his early expeditions to Africa with the famous missionary and traveller, Dr. David Livingstone, the elephants were quite tame, but after a few days' potting with rifles they became exceedingly wary, unapproachable, and dangerous.

Travellers have recorded more or less identical experiences of all kinds of animals in all parts of the world. Numerous examples of animals may be given, which to all intents and purposes reason, and reason acutely. Birds furnish examples of what are to be regarded as reasoning powers from the zoological standpoint. The denizens of the air, as is well known, take great pains to conceal, preserve, and protect their eggs. These they deposit on the ground and in nests. When placed on the ground the eggs for the most part resemble their surroundings, and are very difficult to see. The gulls and terns follow this practice. The hawks build simple, rough nests on high trees and in inaccessible cliffs. The chaffinch builds a beautiful round nest in the secret cleft of a tree, and lines it with the softest materials procurable. The thrush builds its nest in a thorn or other thick bush, and skilfully

plasters its interior with clay, cow-dung, or other plastic material, and little jenny wren seeks some overhanging rock, cave, or cranny, to build her cunning, daintily-constructed bower of bliss. The swallow, most welcome of visitors, builds her nest in the roofs and rafters of outhouses and dwellings, and in many cases provides a glutinous material with which it causes the nest to adhere to a smooth or ill-adapted surface. The jackdaw, ingenious and knowing, selects ruins, chimney corners, &c., for its nest. Occasionally it selects a site such as a slit or narrow window over a ruined stair with no proper foundation. Nothing daunted, it begins and completes its building operations. The nest, when finished, is sometimes perched on nearly a cart-load of extraneous understructure. Birds sometimes build their nests in moving vans and trains.

While the nests of birds of the same kind generally resemble each other in shape, they are often built of the most varied materials. The building of a nest is not necessarily what is called an instinctive or automatic act; on the contrary, it is very often quite the reverse; the selection of the site, the materials, and formation of the nest being largely original.

The eggs of birds afford valuable feeding material, a fact known to magpies, starlings, &c., which hunt for and devour eggs.

The cuckoo is too indolent to rear her own young. She, however, does not lay her egg in a forsaken nest. No, she quietly drops it into a hedge sparrow's or other nest among the other eggs where the parent bird has just commenced hatching.

Fig. 226.

The cuckoo is not an inspired bird, and must be able to put two and two together. She does not drop her egg by accident into another bird's nest.

Many remarkable anecdotes are narrated of reasoning on the part of birds.

Dr. Samuel Smiles, in his life of Tom Edward, the naturalist, tells us in that most charming work that Edward on one occasion, desiring to secure a specimen of the common tern, succeeded in shooting and disabling it. The bird fell in shoal water, and drifted with the tide toward the shore. Other terns, however, came to the rescue, and carried it seawards to a rock. Edward made a detour and reached the rock, and was a second time about to secure his treasure, when lo! the rescuing birds carried the wounded one right out to sea. On another occasion he watched two birds named the turnstone which had discovered a dead fish on the beach. The birds endeavoured to turn it over with the view of securing the grubs, &c., underneath it, but were unequal to the task. Another turnstone appeared, and was welcomed by gestures and peculiar murmuring sounds. To these signs of joy the new-comer replied by similar utterances. The three then took up the task, and one big combined movement had the desired effect, the birds being rewarded with a rich repast.

My late friend, Dr. Fleming, Professor of Natural History in the Free Church College, Edinburgh, told me that on one occasion, while sauntering on the sea-beach in the vicinity of Edinburgh, he had his attention attracted by what appeared curious antics on the part of a crow. The beach was rocky, and the crow was seen to seize what turned out to be a shell-fish and fly up with it to a considerable altitude. It then let the shell-fish drop so as to break its shell. It subsequently swooped down and gobbled up the juicy morsel. These tactics were successfully repeated several times, when a second crow made its appearance on the scene, and perched at a convenient distance from the scene of operations. The second crow permitted the first to fly up with the coveted dainty morsel, but before it could descend, the second crow darted in and secured the prize. The new arrangement succeeded only twice, crow number one flying off apparently disgusted.

The doctor, who was a cautious observer, concluded that crow number one was a young bird, and number two an old one. Granted that this was so, some important considerations remain. How did the first crow know that if the shell-fish were dropped from a height on a rock the shell would be effectually broken? And how did the second crow know that by perching sufficiently near he would have time to dart in and secure the coveted morsel before the first crow could descend? It must have been a case of experience, or of reason, judgment, and memory combined, on the part of both birds.

One of the best examples of reasoning, however acquired, in birds is to be found in the woodpecker of California. This remarkable bird bores in the autumn several hundreds of holes in the bark of a tree, and inserts in each an acorn which is to serve for food during the winter. The wonderful thing is that each particular acorn is placed in a hole which exactly fits it (Fig. 226).

Birds, when feeding their young, often fly long distances to secure the proper food. This is especially true of

sea birds, such as the gull, gannet, cormorant, pelican, and sea-eagle. It also holds true of many land birds, particularly the birds of prey, as the hawks and eagles. A brown eagle carries rabbits, hares, lambs, fawns, &c., to its eyrie in ever-increasing quantity to feed its voracious young.

The skua gull—a pirate among birds—pursues and bullies other gulls until they disgorge the contents of their stomachs, which the skua immediately appropriates.

The lapwing, when hatching and disturbed, adopts the most ingenious artifices to entice the intruder away from her nest. She performs the rôle of a wounded bird which might easily be caught, and flies hither and thither in a distracted, artless way, taking care always to get further and further away from her often ill-concealed and scantily-guarded home. The lure generally succeeds, and when a sufficient distance has been covered, the lapwing suddenly acquires her wonted powers of flight, and in wide and wider sweeps bids the stranger adieu. I have often been so tricked on my native moors in Lanarkshire.

Wild birds, if alarmed, conceal themselves in thickets and on the ground. This is especially true of grouse and partridges, which under such circumstances crouch and lie low. Their colour generally assists in the concealment.

The young of most birds do the same. I have seen a brood of young plovers flatten themselves on the ground at the approach of footsteps, and when they felt they were discovered stretch out their necks and scuttle off at a great speed like young ostriches. I have also seen young wild ducks disappear in a most mysterious way among sedges.

Tame ducks are taught to decoy wild ducks into nets and long alleys with blind ends, where they are readily captured.

Moor hens, when pursued by dogs, or wounded, can sink their bodies in water and display only their beaks. I have known such cases. I remember on one occasion, when shooting wild fowl on Loch Erne, Fermanagh, Ireland, wounding one and marking the spot. On my approach the bird sank and laid hold of the submerged reeds, and in that position I found it dead.

Diving birds swim and fly under water to secure food or escape from danger in the most extraordinary manner.

Crows, when building their nests in a rookery, steal twigs from each others' nests in the most barefaced manner. This is prevented by appointing crow sentinels to keep watch and ward. Crows hold great gatherings or parliaments, and sit in judgment upon delinquents, whom they sometimes peck to death.

Gregarious birds have a sort of language applicable to the exigencies of peace, war, and danger. They also, when feeding, appoint outposts to raise an alarm if necessary. This is well seen in the case of wild geese, curlews, and other wary birds. The males of many wild birds fight for the females. The domestic cock scrapes about and turns up tit-bits for his favourites, and behaves in the most chivalrous and self-denying manner. Young ducks make for the water almost as soon as hatched; young chickens, on the contrary, avoid and abhor it.

The migratory birds follow the seasons, and in many cases perform enormous journeys. When so employed they usually fly very high. The migrations are performed sometimes for nesting purposes and sometimes to increase the food supply.

In the case of swallows, they assemble in great numbers in certain localities in the late autumn, and the migration is not undertaken until the young birds are sufficiently strong and sufficiently trained in flight to undergo the hardships entailed.

There is reason to believe that these migrations, which appear so incomprehensible at the present day, were begun before existing continents were separated by wide seas—when, in fact, the landmarks were more numerous, and not so far removed from each other.

THE SENSE ORGANS AS BEARING ON ADAPTATION AND DESIGN

There is no department of physiology where the division of labour is carried to a greater extent, or where traces of design are more apparent, than in the sense organs of the higher animals (Plates cxxxvi. to cxli. inclusive, pp. 757 to 765). The information conveyed by them to the brain is various and extensive, and they have from this circumstance been aptly designated the five gateways of knowledge.

The sense organs are the vehicles through which primarily all, or nearly all, the knowledge we possess of the external world reaches us. They are the feelers which the brain in the higher animals throws out all over the body, especially the head, to connect the individual with his surroundings or environment.

Traces of sense organs in a rudimentary state make their appearance low down in the scale of being. In such cases they take the form of antennæ or feelers, vibratile hairs supposed to be connected with hearing, imperfect ears, eyes, &c. Most of the lower animals are enveloped in a sensitive skin or integument. In the higher animals

the sensitive skin and sense organs provide a differentiated sensitive surface which connects the individual with all kinds of matter, near and remote. The sense of touch connects him directly with everything with which he comes in contact, whatever its properties and qualities, the sense of taste with tasting or sapid bodies, that of smell with odoriferous substances, that of hearing with bodies sounding or vibrating in space, that of sight with bodies in some cases immeasurably remote.

To the five senses indicated a sixth sense is sometimes added, namely, that of weight or resistance.

The integument or skin is the organ of touch, and, *par excellence*, the organ of sense, as it extends to all parts of the body, and furnishes quite a plethora of knowledge regarding many dissimilar things. The skin, in my opinion, is the precursor and parent of all the other sense organs; these being mere differentiations and elaborations in special directions and for special purposes.[1]

The sense of touch, though in some respects the simplest, nevertheless excels all the other senses in the variety of subjects with which it deals. Thus it can inform us whether a body is solid or liquid, hot or cold, rough or smooth, hard or soft, large or small, &c.

The differentiation so observable in the sense organs as a whole begins in the skin itself. The skin is not, as one would naturally suppose, equally sensitive in all its parts. On the contrary, some parts of the body are exquisitely sensitive, while others are comparatively insensitive. Thus the anterior surface of the body and the palms of the hands and soles of the feet are more sensitive than the posterior surface of the body and the dorsal surfaces of the hands and feet. The apertures of the body are more sensitive than the surrounding skin; the tip of the tongue and the tips of the fingers, than the cheeks; the cheeks, than the back, and so on.

The precise degree of sensitiveness can be accurately ascertained by applying a pair of compasses with rounded points to different parts of the skin. The most sensitive parts can recognise the points of the compasses as two separate bodies when they are less than the twenty-fourth of an inch apart; this is the case with the tip of the tongue. In the case of the back the points of the compasses require to be separated for more than two inches before they can be detected as two distinct bodies.

The following measurements in Paris lines (twelfths of an English inch) are by Valentin:—

Degree of Sensibility in Various Parts

	Paris Line
At the tip of the tongue	·483
At palmar surface of tip of fingers	·723
At palmar surface of second phalanges	1·558
At palmar surface of first phalanges	1·650
At dorsum of tongue	2·500
At dorsal surface of fingers	3·900
At cheek	4·541
At back of hand	6·966
At skin of throat	8·292
At dorsum of foot	12·525
At skin over sternum	15·875
At middle of back	24·208

The increased sensitiveness in the tips of the fingers is due to the presence of a great variety of nerve endings; the nerves in these parts terminating in free ends, loops, various end bulbs, and Pacinian bodies. The Pacinian bodies, which are rounded and ovoid in form and about the size of a millet seed, are very remarkable structures. They consist of concentric layers of nucleated fibrous tissue, and enclose in their interior a hollow space containing fluid, in which the axis-cylinder of the sensory nerve spreads out and terminates. In other end bulbs the sensory nerve winds spirally round the outside of the bulb; in a third form the sensory nerve terminates in loops on the end bulb. By these means the sensitiveness of the part is very greatly exalted. The Pacinian bodies in some respects resemble the eye, the concentric fibrous coats representing the sclerotic covering of the eye; the enclosed fluid, the vitreous humour; and the axis-cylinder with its expansion, the optic nerve and retina. When a Pacinian body is touched the impact travels through the false or scarf skin to the corium or true skin, with the result that the fluid contents of the Pacinian body situated in the corium surge in waves against the central and most delicate portion of the sensory nerve. The most sensitive part of the sensory nerve is touched by a fluid impact, which is the

[1] "The eyes are formed by a diverticulum which grows out on each side from the first cerebral vesicle. This diverticulum is at first hollow, its cavity communicating with that of the hemisphere. Afterwards the passage between the two is filled up with a deposit of nervous matter, and becomes the *optic nerve*. . . . The crystalline lens is formed in a distinct follicle, which is an offshoot of the integument, and becomes partially imbedded in the anterior portion of the globe of the eye. The cornea also is originally a part of the integument, and remains partially opaque until a very late period of development. Its tissue clears up, however, and becomes perfectly transparent, shortly before birth. . . . The eyelids are formed by folds of the integument, which gradually project from above and below the situation of the eyeball. . . . The internal ear is formed in a somewhat similar manner with the eyeball, by an offshoot from the third cerebral vesicle, the passage being filled up by a deposit of white substance, which becomes the auditory nerve. The tympanum and auditory meatus are both offshoots from the external integument." ("Treatise on Human Physiology," by John C. Dalton, M.D., Professor of Physiology and Hygiene in the College of Physicians and Surgeons, New York. Philadelphia, 1871.)

softest and kindliest of all impacts. Fluid impacts are the rule in all the sense organs, and especially so in the eye and ear. The savoury and odoriferous substances are each dissolved and reduced to a semi-fluid form before acting on the gustatory and olfactory nerves, and the retina or expansion of the optic nerve and the terminal filaments of the auditory nerves are literally bathed with fluids, to wit, the vitreous humour and endolymph.

The nerves of the skin and their adjuncts, on which the sense of touch depends, are to be regarded as nerves of sensation pure and simple. They convey impressions of external objects from the skin to the spinal cord and brain, where the sensations are recognised or perceived. The sensations travel from without inwards, and the sensory nerves, carrying as they do information from without inwards, have been appropriately termed *afferent* nerves. They are distinguished from the motor nerves, which extend between the brain and spinal cord and the muscles. As the motor nerves carry impulses, volitions, &c., from the brain and spinal cord from within outwards, they are called *efferent* nerves. In the senses of taste and smell, sensory and motor nerves and muscles are all brought into requisition. The food is to be felt and moved about in the mouth by the muscles of mastication and the tongue; the smelling bodies are to be sniffed into the nostrils by muscular efforts. However refined or sublimated the special sense organs may be (those of hearing and seeing included), they have as accessories ordinary sensory and motor nerves and muscles. They are necessary for purposes of adaptation, and in some cases for initiation. The ear in hearing must be strung up to an extraordinary degree of nicety by muscular movements, and muscular action alone can enable the eye to accommodate itself to distances near and remote.

It is customary to speak of the sense organs as being something altogether special—that is, neither sensory nor motor; but this is scarcely accurate, for all the sense organs are primarily and fundamentally touch organs, and convey information from without. The sense organs may, or may not, avail themselves of their direct or indirect connection with the motor or efferent nerves and the muscles to which they are distributed, but the rule is that the sensory and motor nerves are complemental structures, and that both are the satellites of the brain and spinal cord; the one brings information to the individual through the spinal cord and brain, and it is for the individual to avail himself of it and to act or not as he pleases.

The manner in which the sensory and motor impulses travel, and the mode in which the sensory impulses are converted into motor impulses in the brain and spinal cord by nerve cells, ganglia, neurons, &c., are not yet quite made out. Experiment and observation, however, render it all but certain that the phenomena witnessed are in every instance physical in character, and due to atomic and molecular changes occurring in the structures concerned, namely, the sensory and motor nerves, and the intervening nerve cells, ganglia, neurons, &c. Thus in the case of the sensory nerves the sensation is transmitted by a series of molecular changes occurring in the substance of the nerves, the molecules acting upon each other in a direction from without inwards; in the case of the motor nerves the impulse is transmitted in a similar but opposite direction, the molecules acting upon each other in a direction from within outwards.

The molecular changes occurring in the nerve cells, ganglia, neurons, &c., in the brain and spinal cord are of two kinds, namely—

(*a*) Spontaneous and direct brain changes, which result in volitions, and

(*b*) Mechanical, indirect, spinal cord changes, which result in so-called reflex acts.

Our conception of the senses, sense organs, and their mode of working will be greatly simplified by bearing in mind that we are in every instance dealing with matter: matter inside and outside of ourselves; matter near and remote; matter in the form of gases, fluids, semi-fluids, solids; matter visible and invisible, &c. There is no mystery in the operation of the sense organs if it be remembered that they are in every instance material structures, and are, in every case, acted upon by material particles more or less minutely divided and more or less widely separated. There is no getting away from matter in this world. The matter which acts by way of impact upon the skin, the mouth, and the tongue is, as a rule, palpable; that which acts upon the nose is more finely divided and less palpable, that which acts upon the ear being still more tenuous (the material atmosphere thrown into waves), that which acts upon the eye being the most subtle of all matter, namely, the ether in a state of vibration.

The peculiarity of the sense organs consists in this, that they are expressly constructed to appreciate different kinds of matter. Thus the light affects the eye to a greater extent than it does the skin; bodies which are sounding or in a state of vibration affect the ear and not the eye; savoury and smelling bodies affect neither the eye, the ear, nor the skin. The skin, the tongue, and the nostrils cannot detect light, neither can the eye detect sound, or the converse.

Here there is a marvellous degree of differentiation and adaptation of means to ends. The living matter of the higher organisms—especially that of man—is endowed with what may almost be designated divine attributes. By elaborations of the most skilful and extraordinary kind one part of the body is made to feel, another to taste, another to smell, another to hear, and another to see. The higher organisms are brought into contact, by the aid

of the senses, with every conceivable kind of matter, near and remote: they are in a position to deal with matter in all its forms. The sense organs and the brain separate the higher organisms from the inorganic kingdom and the matter it contains. The sense organs place the higher organisms in a coign of vantage, and permit them to survey and take advantage of inanimate nature in every direction. They give to the higher animals, and to man in particular, their authority and power to rule. The sense organs are to be regarded as original endowments—fundamental gifts—special adaptations—creations to confer knowledge and power on their fortunate possessors.

I am aware that there are those who believe that the eye was not specially created to recognise the light and the innumerable and interesting objects which it reveals, but that, on the contrary, the eye was fashioned by the light; the dead thing being credited with the formation of the living thing. Those who indulge in this kind of reasoning say that, in like manner, the ear was not planned and constructed to recognise the presence of bodies sounding or vibrating in space, but that the atmospheric waves made by the vibrating bodies produced the ear. In like manner they affirm that savoury bodies formed the taste organs, and odoriferous particles the smelling organs. This theory is too absurd and fantastic to be seriously considered. If it were true, one would expect to find every part of the body which the light touches crowded with eyes, and every part assailed by sound waves bristling with ears. There could not possibly be the localisation of the sense organs which obtains, and (what is even more important) there could not be the direct connection between the sense organs and the brain which gives them their special value.

§ 234. The Sense of Touch.

This sense is fundamental, and may be regarded as synonymous with general sensibility or the power of feeling. A stone is said to be insensate or devoid of feeling. It is otherwise with plants and animals. Quite a large number of plants, and by far the greater number of animals, as has been shown, feel.

Certain sensitive plants (Venus's flytrap and the sundew, for example) feel the insects which alight on them; they also seize and devour them. Similar remarks are to be made of the lowest animal forms, amœba, *Gromia*, &c.

A nervous system such as we behold in the higher animals is not a necessary accompaniment of feeling in plants and the lower animal forms.

Where, however, a nervous system exists, we naturally turn to it for an explanation of the kind and degree of sensibility. The structures to be examined in connection with the sense of touch are the external skin or common protective covering of the body, the sensory nerves of the skin, the various forms of nerve endings, end bulbs, Pacinian bodies, &c. (Plate cxxxvi., p. 757).

The integument or external skin is a highly interesting and complex structure. In the higher animals it combines the functions of protection, sensation, and excretion, and consists of two parts, namely, the *epidermis* or false skin, also called cuticle or scarf skin; and the *dermis* or true skin, also called corium. The internal skin or mucous lining which invests the mouth and nostrils performs the same rôle in the organs of taste and smell which the external skin performs in the organs of touch.

The *epidermis or scarf skin* is placed above or over the *dermis or true external skin:* it is insensitive and non-vascular; if wounded it neither gives pain nor bleeds. The epidermis consists of a superficial and a deep portion—the superficial part, which is more or less horny, being composed of flattened epithelium scales placed horizontally; the deeper part, the so-called mucous layer (rete mucosum or Malpighian layer), being of a more delicate texture, and composed of several strata of rounded cells placed vertically. The cells of the deeper part ultimately change their shape, position, and chemical constitution to take the place of the cells of the superficial part, which latter are being constantly shed from the surface of the body. The epidermis or scarf skin furnishes, perhaps, the best example of the changes continually going on in all parts of the body. The epidermis, while it affords mechanical protection to the body, furnishes by the impermeability of its horny layer a protection against the absorption of poisons.

The dermis or true skin differs from the epidermis or false skin in being highly sensitive and highly vascular. It, moreover, presents a highly complex structure, consisting as it does of fibrous tissue, fat, blood-vessels, nerves, touch corpuscles, Pacinian bodies, sweat glands, sebaceous glands, hairs, &c.

The surface of the dermis or true skin is thrown into papillæ or finger-like prominences, the largest of which are about the one-hundredth of an inch in length. The papillæ are for the most part arranged in lines, and produce ridges and furrows well seen in the palms of the hands and the soles of the feet. The superficial part of the dermis is much more vascular than the deeper part, and contains one of the richest networks of capillary blood-vessels in the body, a loop of blood-vessels being furnished to each papilla.

"The sensibility of the skin is due to the presence of nerve terminations, which are of different descriptions

and at different depths. The largest of these are termed *Pacinian bodies*, and are especially found in the subcutaneous adipose tissue of the fingers and toes. They are grape-shaped structures, of such size that they can be recognised by the practised dissector with the naked eye as minute grains, being upwards of a sixteenth of an inch in length: and they consist each of a dilated end of a nerve fibre, with layers of tough nucleated tissue round about. . . .

"Within a number of the papillæ of the dermis or true skin smaller bodies are found, termed *touch corpuscles* of Wagner. . . .

"These are of such size, that each one fills the greater part of the papilla in which it is contained: the structure consists of a firm nucleated core, round which the nerve is coiled. . . .

"Still smaller *end bulbs*, namely, those of Krause, are found in or beneath the papillæ in places where the skin is delicate, as on the lips, and over the white of the eye, and appear to resemble the Pacinian bodies in having the nerve end in the interior. . . . Lastly it is to be noticed that independently of all these modes of nerve termination, nervous filaments have been found to terminate in loops and very delicate hair-like processes—others ramifying between the cells of the epidermis, and possibly terminating in individual cells; and, although this is the most difficult method of nerve termination to trace, there can be little doubt that it is the most important." [1]

The sensory apparatus, it will be perceived, is even in the skin very elaborate, and quite sufficient to account for the refined sensibility exhibited by various parts of the external surface of the body.

The Pacinian bodies represent the highest form of touch corpuscles, and deserve very special attention from the fact that they heralded or prefigured, as explained, all the higher sense organs. Each Pacinian body, as stated, is composed of concentric layers of nucleated fibrous tissue. Each contains in its centre an open space filled with fluid. This fluid cavity receives the core or most sensitive part of the sensory nerve.

By this arrangement the area of the feeling surface is increased, and the most sensitive part of the sensory nerve protected from injury.

Needless to say, the most delicate impact that can be communicated to a sensitive nerve *is a fluid impact.*

If a foreign body be made to touch the skin it necessarily impinges against one or more of the Pacinian bodies; but the Pacinian bodies, being set in motion, cause the fluids which they contain to surge in waves against the exposed, highly sensitive, expanded terminal filaments of the sensory nerves. In touching the skin *directly*, the Pacinian bodies and their contained fluids and nerves are touched *indirectly*.

No more delicate or beautiful arrangement can be conceived. It is a remarkable fact that fluids are necessary in every instance to the manifestations of the senses in the higher animals. Thus in the eye and ear, fluids are in contact with the ultimate expansions of the optic and auditory nerves, and in the nose and tongue the smelling and sapid bodies are literally dissolved upon and penetrate the ultimate filaments of the olfactory and gustatory nerves.

Four things are necessary for the normal action of the sense organs. (*a*) Sensory nerves: (*b*) fluids bathing these nerves; (*c*) foreign bodies of some sort; and (*d*) impacts produced by said foreign bodies.

Sensations are definite or indefinite according to the degree of localisation. While they are in every case the result of nerve impact, the impact may be produced by bodies outside or inside ourselves. Thus we may experience a vague and undefinable sensation of restlessness, fatigue, faintness, discomfort, &c. We cannot trace the sensation to its source, still we are conscious of its existence. The feelings of hunger and thirst furnish examples of vague sensations in so far as they are not localised, and affect the whole body, and nearly every part of the body alike. Hunger and thirst are not, as is generally supposed, confined to the stomach. These vague sensations convey no information of the outside world—they are to be regarded as subjective in their nature.

"What is termed the *muscular sense* is less vaguely localised than the preceding, though its place is still incapable of being accurately defined. This muscular sensation is the feeling of resistance which arises when any kind of obstacle is opposed to the movement of the body, or of any part of it: and it is something quite different from the feeling of contact or even of pressure." [2]

Thus if a feather be placed in the palm of the hand we are aware of the contact of a foreign body, but we cannot gauge its weight or estimate the amount of pressure produced by it. The conditions, however, are changed if we replace the feather by a leaden bullet of a few ounces in weight; then we are conscious not only of the presence of a foreign body, but of a heavy body and a certain amount of resistance.

The sensations peculiar to the skin are localised, and consequently more definite. Thus if an object be made to touch the skin we know what portion of the body is touched. We further know whether the object is hot or

[1] "Animal Physiology: the Structure and Functions of the Human Body," by John Cleland, M.D., F.R.S., &c., Professor of Anatomy and Physiology, Queen's College, Galway, p. 68. 1874.

[2] "Elementary Physiology," by Thomas H. Huxley, LL.D., F.R.S. London, 1885, p. 203.

cold, soft or hard, rough or smooth, liquid or solid, and so on. We arrive at this knowledge by an actual impact made upon the skin in the following manner. The foreign body which produces the sensation touches the epidermis or false skin, and this in turn touches the dermis or true skin, in which the terminal filaments and touch corpuscles of the sensory nerves are situated. The epidermis is therefore not the originator of the sensation, but the transmitter thereof.

It is intermediate between the physical object which produces the impact and the sensory nerve which receives it. The epidermis protects the delicate sensory nerves from injury, and conveys in a readily appreciable form every variety of external impression.

That the epidermis performs this rôle in sensation is evident from this. If the epidermis be removed by accident or design, as by blistering, a raw surface is produced, which, if touched, results not in an ordinary sensation but in a painful impression.

An intermediate agent of some kind is necessary, not only in the skin, but in all the sense organs.

The eye is placed between the terminal filaments of the optic nerve and the light; and the ear is placed between the terminal filaments of the auditory nerve and the sounding or vibrating body. The eye and the ear are connecting media; they are to the senses of seeing and hearing what the epidermis is to the ordinary skin of the body.

Skin sensations are remarkable in this, that they may be produced by a great variety of objects, all of which characteristically differ. It is otherwise with the special sense organs, which are elaborated and modified to deal only with certain kinds of matter and no other. The eye takes cognisance of the vibrating ether and light; the ear of the vibrating air and the waves of sound.

It is necessary to distinguish between the physical objects of the sensation and the sensory nerves which convey the knowledge of the sensation to the brain, where it becomes a perception. Sensation, perception, and consciousness naturally merge into each other. Sensation is to be regarded as feeling localised in a part, perception the feeling realised by the brain, and consciousness the knowledge of our own existence and of the existence of things outside of ourselves.

I have alluded to the power which the sensory nerves of the skin possess of distinguishing between hot, cold, rough, smooth, hard, soft, and other bodies, and it becomes a question whether it is not an error to regard touch as the lowest of all the senses.

The eye can only deal with the luminous ether, the ear with sound waves, the nose with odoriferous particles, and the tongue with sapid substances. The skin, however, as stated, can distinguish between quite a large number of bodies, each having its own physical properties.

The sense of touch is an original endowment, and is fundamental; it is here that plants approach the lowest animals, and that the lowest animals approach the highest, man included.

A child chiefly employs the sense of touch; it feels and handles everything; it trusts its other senses very little to begin with. The sense brought into requisition after touch is that of taste; the child tries to cram everything it gets hold of into its mouth. The nose, the ears, and the eyes are not of much account at first. They are brought into play further on. They develop their peculiar powers as the child grows. It is very interesting to watch a child trying to accommodate its eyes to distance. It makes some curious mistakes, which are only corrected after repeated trials. All the sense organs require to be trained, and the training consists in voluntary efforts frequently repeated. The sense organs only become efficient when a very intimate connection is established between the sensory and motor nerves and their intermediary muscles. This connection, which is at first voluntary, becomes latterly involuntary or automatic. The voluntary acts become, by constant and frequent repetition, what are spoken of as reflex acts. This is well illustrated by a study of the nerve and muscular arrangements of the sense organs. The movements required for talking, smelling, hearing, and seeing are associated, co-ordinated movements—movements to given ends.

The sense of touch gives information regarding bodies *at very short distances;* the same holds true of the sense of taste. The senses of smell, of hearing, and of seeing, on the other hand, place us in communication *with objects at a distance.* The dog can scent a deer a long way off; the Indian, by placing his ear to the ground, can detect sounds, or, what is the same thing, sounding bodies, many miles off; and the eye of the astronomer, aided by the telescope, can detect heavenly bodies at immeasurably remote distances.

In all this there is order and design. Plants and the lowest animal forms only require a knowledge of their immediate surroundings: the higher animals require a knowledge of a more extended area, and man is privileged to contemplate not only the planet he inhabits, but an incalculable number of other planets, some of which are immeasurably distant.

A question naturally arises here as to how far the sense of touch is to be trusted. Is the sense of touch

infallible? By no means. It, like all the other senses, is capable of being deceived. An educated touch, however, is less liable to err than an uneducated one; a remark which applies also to the other senses.

The sense of touch and all the other senses supply only *comparative* information. If the surroundings—that is, the conditions—are changed the information supplied varies. Thus if three basins containing ice-cold, hot, and lukewarm water are exposed, and the hand thrust into them alternately, the lukewarm water will appear cold after the hot water but warm after the cold water. This is due to the fact that a sensation does not pass away the instant it is generated.

It is, further, often impossible to distinguish between a very hot and a very cold body. Similar remarks may be made of all the other senses: they are all liable to be deceived. Thus the sense of taste cannot distinguish between port, sherry, and other wines if they are tasted in rapid succession for several times. The nose cannot distinguish between different scents if they are sniffed in rapid succession. The ear cannot detect the position of a sounding body in a fog, and a mist distorts and magnifies images to the eye. A swallow emerging from the mist sometimes assumes the appearance of, and looks as large as, a good-sized hawk. The mirage of the desert actually deceives the eye.

These are curious points, but they are not inexplicable if we only bear in mind that in order to have uniformity of impressions the sense organs must be healthy, the conditions exactly the same, and a certain interval of time allowed to them duly to interrogate the bodies presented to them.

All the sense organs are capable of being educated. The skin of the fingers of the needlewoman and of the watchmaker is more sensitive than that of the outdoor worker. The palate of the gourmet can distinguish the flavours of delicate foods and wines which would escape the notice of ordinary people; the connoisseur in scents at once detects impurities; the trained ear of the musician is pained by discordant notes; and the educated eye can determine the colour and the relative sizes of objects, and the distances between them, to quite an extraordinary extent. The eye, aided by the microscope and telescope, can recognise the smallest and largest bodies; can grasp the infinitely little and the infinitely great; the marvels of the most minute particles of matter and the wonders of the most ponderous as seen in the great planetary system.

§ 235. The Sense of Taste.

The sense of taste greatly resembles that of touch. It differs little from general sensibility as manifested by the skin and mucous linings generally. In the first place the organ of taste is simply a portion of the mucous membrane beset with vascular and nervous papillæ similar to those of the general integument. Secondly, it conveys impressions of such substances only as are in actual contact with the sensitive surfaces. It establishes no communication with objects at a distance. Thirdly, the surfaces in which the sense of taste inheres are endowed with general sensibility. Fourthly and lastly, there is no special nerve of taste; this property residing in portions of two different nerves, namely, the fifth pair and the glosso-pharyngeal (eighth pair); but these nerves supply general sensibility to the mouth and surrounding parts.

The sense of taste is confined to the mucous membrane or internal skin of the tongue, the soft palate, and the fauces. The tongue is more especially the organ of taste. The mucous membrane of the fauces and posterior third of the tongue is covered with minute vascular papillæ analogous to those of the skin. They, however, do not project, but are embedded and concealed in the smooth layer of epithelium forming the surface of the organ.

At the junction of the posterior and middle thirds of the tongue there is a double row of rounded eminences arranged in a V-shaped figure (the circumvallate papillæ). In front of this the upper surface of the organ is everywhere covered with an abundance of thickly-set, highly-developed papillæ, which project from the surface of the tongue and confer on it a more or less velvety appearance. The papillæ of the tongue are divided into three sets, namely, the filiform, the fungiform, and the circumvallate. The filiform papillæ are the most numerous, and cover the entire upper surface of the tongue. They are long, slender filaments, covered with a somewhat horny epithelium. They terminate in a filamentous tuft.

The fungiform papillæ are of a rounded, club-shaped form, and are covered with a soft permeable epithelium. They are thicker and larger than the filiform ones.

The circumvallate papillæ are rounded prominences, which, as stated, form a V-shaped figure near the foramen cæcum. They vary from eight to ten in number, and are each surrounded by a wall or circumvallation of mucous membrane, and hence their name.

Over and above the papillæ referred to, there are, in certain cases, the so-called taste buds. These are rounded, oval bodies resembling the end bulbs of the skin. They are situated in clefts or depressions of the mucous lining

of the tongue near the surface, and are supplied with the nerves of taste, which proceed to the papillæ and other taste organs.

The sensitive nerves of the tongue, as indicated, are two in number, namely, the lingual branch of the fifth pair and the lingual portion of the glosso-pharyngeal (eighth pair). The lingual branch of the fifth supplies the anterior two-thirds of the tongue ; the lingual portion of the glosso-pharyngeal the posterior third. These nerves divide into various branches, and ultimately terminate by delicate loops and free extremities in the papillæ of the tongue. They confer on the tongue its special sense of taste, and likewise a certain degree of general sensibility. The tongue is consequently able to distinguish between sapid bodies, and those which are not sapid ; that is, bodies possessing ordinary physical properties. There is reason to believe that the tongues of animals which swallow their prey whole are possessed only of general sensibility. The parts of the tongue most sensitive to savours are the base, tip, and edges. The sense of taste, however, resides in the whole superior surface, the point and edges of the tongue, the soft palate, fauces, and part of the pharynx.

Division of the fifth pair of nerves destroys the sensibility of the anterior two-thirds of the tongue. After this operation, this part of the tongue may be scarified without producing pain. Division of the glosso-pharyngeal enables animals to eat all sorts of bitter food without knowing it.

In addition to nerves, blood-vessels, &c., the tongue and contiguous textures are furnished with numerous mucous follicles which supply a viscid secretion. This lubricates the parts, and by keeping them soft contributes to the sense of taste. The mucous glands are found at the base, edges, and under surface of the tongue near the tip, and in the mucous membrane of the mouth and fauces generally.

The muscles of the tongue are complicated and numerous, and admit of the organ being moved in every direction. They are arranged on the same plan as those of the heart and hollow viscera. The more mobile the tongue the better it is adapted as the organ of taste, from the fact that it can the more readily accommodate itself to receive impressions of all kinds from sapid bodies.

From the foregoing it will be evident that we must distinguish between the special impressions derived from the sapid qualities of bodies, and the general sensations produced by their ordinary physical properties.

The sapid qualities are, strictly speaking, the only ones which we perceive by the sense of taste.

We perceive the physical qualities of the solids and fluids used as food by the general sensibility of the tongue, palate, and fauces. The physical and sapid qualities of food are not to be confounded. Thus starchy substances are viscid, and in many cases tasteless, or all but tasteless. Red pepper and other irritating condiments are not tasted —they act upon the general sensibility of the parts. Wines, again, are at once tasted and smelt. Hence we speak of the bouquet of a wine. In this case a great part of what we call the taste is due to the aroma or smell which reaches the nares or back parts of the nostrils during the act of swallowing. This power of distinguishing the aroma of the solids and fluids used as food is vitiated when we suffer from cold, influenza, &c. ; under these circumstances finely-flavoured foods and wines are not appreciated. The smell of freshly-cooked meat at once provokes the appetite, and contributes to the enjoyment of the meal. The savours are spoken of as sweet, bitter, sour, alkaline, salt, &c.

§ 236. Conditions under which Taste is Experienced.

Substances in order to be tasted must be reduced to a fluid or semi-fluid form. If they are not dissolved their physical properties only can be perceived. A marble cannot be tasted, a sugar-plum can. It is only the liquid and soluble portions of our food which are tasted, such as the animal and vegetable juices and the soluble salts.

The sapid substances in a state of solution must come actually in contact with the gustatory apparatus. This effect is produced by a process of osmosis ; the sapid liquids passing by endosmosis into the lingual papillæ, taste buds, &c., so as to come in contact with the ultimate filaments of the taste nerves. This process is facilitated by the presence of saliva and mucous secretions in the mouth ; the sense of taste, as indicated, being greatly impaired if the mouth and fauces be dry, as in catarrh and inflammatory conditions of the throat and mouth. As the muscular movements of the stomach are necessary to a perfect digestion, so the muscular movements of the tongue are indispensable to a just appreciation of sapid substances. If a sapid body be spread as a dry powder on the tongue little effect is produced. It is only when the tongue presses it against the roof of the mouth, palate, and other parts that its full flavour is realised. The movements of the tongue force the saliva and other fluids into the dry substance, and so extract its flavour. The nervous papillæ and taste buds of the tongue are to be regarded as the essential organs of taste ; the lingual muscles as important auxiliary organs.

While the tongue and palate suffice for tasting a sapid substance, its full flavour is only realised when the substance is swallowed. This is due to the fact that in the act of swallowing the food is pressed against the extensive

surfaces of the fauces and pharynx by the constrictor muscles of those parts, and in this manner with the terminal filaments of the gustatory nerves. Pressure and motion facilitate osmosis, and as a consequence contribute largely to the production of taste.

The impressions made on the tongue and adjacent parts by sapid bodies remain for a certain time after the bodies themselves are removed. As a consequence sapid substances tasted in rapid succession are apt to be confused with each other. This is the case, for example, with wines. If a wine-taster be blindfolded and three different wines presented to him in rapid succession, as pointed out, he soon fails to recognise the three primary flavours. The same remarks apply to the tasters of tea, &c.

If a highly-flavoured and pungent substance be held in the mouth for a short time and then ejected, a nauseous drug may be swallowed immediately after without any feeling of nausea. This is due to the fact that the taste of a body remains for a short time after the substance itself is gone.

§ 237. The Sense of Smell.

The so-called olfactory nerves, on which the sense of smell depends, are, as already stated, nervous commissures which connect the olfactory ganglia with the central parts of the brain. The nerve masses situated upon the cribriform plate of the ethmoid bone consist of grey matter, and even the filaments which they send to the mucous membrane of the nose are grey and gelatinous in texture, and in this respect different from ordinary nerve fibres. The olfactory nerves convey the special sensation of smell to the brain. If they be stimulated artificially no pain is experienced, and no muscular motion produced.

The organ of smell consists of the following parts :—

(*a*) The olfactory ganglia.
(*b*) The olfactory nerves, commissural in character.
(*c*) The terminal filaments of the olfactory nerves in which the sense of smell resides.
(*d*) The mucous membrane of the nasal passages in which the olfactory nerve filaments terminate.
(*e*) The nasal passages with the turbinated bones and the muscles of the anterior and posterior nares.
(*f*) The mucous follicles, situated more especially at the upper part of the nasal fossæ.

The mucous follicles exude a secretion which keeps the mucous surfaces in a moist and sensitive condition. The mucous membrane of the upper part of the nasal fossæ is soft, thick, spongy, and vascular. It is the only part which receives filaments from the olfactory nerves, and which is capable of appreciating the impressions of smell. It is from this circumstance designated the *olfactory* membrane. The mucous membrane of the lower part of the nasal fossæ is less spongy and vascular than the upper part, and is known as the *Schneiderian* membrane.

The filaments of the olfactory nerves are distributed to the mucous membrane of the superior and middle turbinated bones and the upper part of the *septum nasi.* They are soft in consistence and grey in colour, and disappear in the mucous membrane after freely dividing and ramifying in all directions. If these filaments be divided the sense of smell is destroyed.

Other nerves besides the olfactory are distributed to the nasal passages. Thus the nasal branch of the ophthalmic division of the fifth pair supplies the mucous membrane of the inferior turbinated bone and the inferior meatus, while the spheno-palatine ganglion of the great sympathetic sends filaments to the whole posterior part of the nasal passages and the levator palati and azygos uvulæ muscles. The muscles of the anterior nares are supplied by filaments of the facial nerve.

The organ of smell, as will be seen, is provided with sensitive nerves from two different sources, namely, at its upper part with the olfactory nerves proper derived from the olfactory ganglia ; secondly, at its lower part with the nasal branch of the fifth pair. The former are nerves of special sense ; the latter of general sensibility. The sense of smell differs from the sense of taste in this, that it gives us intelligence of the physical properties of bodies in a *gaseous* or *vaporous* condition. In other words, an odorous substance may be detected at a distance and when unseen. This is no doubt due to the fact that all bodies exposed to the air are constantly disintegrating and giving off particles. These become diffused in the atmosphere, and being drawn into the nasal passages in the act of breathing, and when sniffing, are made to impinge against the terminal filaments of the olfactory nerves. In this way multitudes of infinitely minute particles assail the mucous membrane of the nose. As the impact is exceedingly delicate, it is not perceived by the nerves of general sensibility, but only by the nerves of special sense. The impressions, however, made on the two kinds of nerves differ less in kind than in degree.

There is (and it is worthy of note) a greater gap between the nerves of special sense and those of general sensibility in the organ of smell than in the organ of taste. As a matter of fact, the nerves of special sense and general sensibility occupy different parts of the nasal passages.

§ 238. Conditions under which Smell is Produced.

In order to realise the odour emanating from any smelling body, the particles which the smelling body gives off, and which are so attenuated as not to be appreciated by their weight, must be freely drawn through the nasal passages. The nasal passages must, moreover, be moist, so that the odoriferous particles may be dissolved on the mucous membrane in which the olfactory nerves terminate. Here there is actual contact—parts of the odoriferous substance in an extremely minute state of division passing by endosmosis into, and becoming incorporated with, the terminal portions of the olfactory nerves.

If, as explained, the mucous membrane of the nose be dry or inflamed, and thickened from any cause, the sense of smell is impaired and even temporarily destroyed. The power of distinguishing odours varies according to the state of the health and the condition of the parts. In man the sense of smell is inferior to that of many of the lower animals. Dogs, for example, can distinguish between the several kinds of game in the forest, and can follow a trail with unerring certainty for inconceivably long distances. Man has no such power. In such cases he depends wholly upon the senses of sight and hearing. When the Indian tracks an enemy he stoops, listens, and looks. He is quick of hearing, and can detect distant sounds ; he is sharp of sight, and can distinguish a footprint imperceptible to ordinary eyes.

Odours may be divided into true and false. True odours affect the olfactory nerves ; false odours those of general sensibility. The latter are, as a rule, irritating substances.

Sometimes the true and false odours are blended. Thus Eau de Cologne possesses odoriferous and irritating properties, the former due to the vegetable ingredients it contains, the latter to the alcohol. The same may be said of wines.

Smell and taste have certain features in common. Thus wines and other odoriferous liquids and solids are smelt while being swallowed. Thus there are sweet and sour smells as well as sweet and sour tastes. Again, the sensation of smell, like the sensation of taste, remains for a short period after the substance which caused it is removed. It is owing to this circumstance that odours become blended, and a difficulty is experienced in distinguishing between them.

§ 239. The Sense of Hearing.

The auditory nerves, on which the sense of hearing mainly depends, contain vesicles or cells as well as nerve fibres, and are commissural in character. In this respect they resemble the olfactory and optic nerves. The auditory, like the olfactory and optic nerves, are destitute of ordinary sensibility, and are apparently only capable of transmitting impressions of atmospheric sound waves.

Sound waves are produced as follows. Sonorous bodies, such as bells, tuning-forks, drums, violins, guitars, &c., are thrown into a state of vibration by being touched or struck ; the sonorous bodies communicate their vibrations to the atmosphere which invests them on all sides. The air vibrations, which take the form of successive waves, spread from the sonorous bodies in ever-increasing circles until they reach the ear, where they impinge against the ultimate filaments of the auditory nerves in a manner to be presently explained. Sound waves produced by bodies vibrating in space vary in intensity according to the magnitude and distance of the vibrating substance. The report of a cannon is better heard than the stroke of the woodman's axe or the quarryman's hammer. In like manner the beating of a drum produces a greater noise than the shaking of a tambourine. Sound waves, however produced, are essentially the same ; the high or low pitch of the sound being in every case determined by the number of vibrations in a given time.

The sense of hearing interprets the vibrations produced in the air by every kind of sonorous body.

The air vibrations are of such a character that they cannot be appreciated by the nerves of ordinary sensibility. Their existence, however, is placed beyond doubt by physical experiments. Similar vibrations may be communicated to water, so that many aquatic animals are endowed with the organ of hearing. Fish may be collected at feeding time by the sounding of a gong. The auditory apparatus in the higher animals is very complicated. In man it consists of the following parts (Plate cxxxix., p. 762) :—

(*a*) The external ear, consisting of a funnel-shaped, cartilaginous framework which collects the sound from the atmosphere. This framework can in certain cases be moved, in a variety of directions, by muscles provided for the purpose.

(*b*) The external auditory meatus or passage (a tube or canal an inch in length), which extends from the external ear to the membrana tympani, the so-called drum of the ear. This tube is partly cartilaginous and partly bony, and is provided with hairs and a ceruminous secretion, which prevents the ingress of foreign bodies into the ear.

(*c*) The membrana tympani, or drum of the ear, a thin fibrous membrane stretched across the bottom of the

external auditory meatus. This membrane receives the sonorous vibrations or air waves which enter the external ear (see *membrana tympani*, Fig. 227).

(*d*) The cavity of the middle ear, situated between the membrana tympani or drum and the membrane closing the foramen ovale.

The membrane closing the foramen ovale forms a second and sort of inner drum for the ear. It has fluid on its inner side and air on its outer side, and in this respect differs from the membrana tympani, or real drum of the ear, which has air both on its inner and outer sides.

The cavity of the middle ear communicates posteriorly with the mastoid cells, and anteriorly with the pharynx, by a narrow passage lined with ciliated epithelium and running downwards, forwards, and inwards, called the *Eustachian tube*.

The cavity of the middle ear is remarkable in this, that it contains a chain of small bones called the malleus, incus, and stapes, from their resemblance to a hammer, an anvil, and a stirrup respectively. These form a line of communication between the membrana tympani and the membrane closing the foramen ovale. By means of these bones every form of vibration occurring in the membrana tympani is at once transmitted to the membrane closing the foramen ovale. The degree of tension in the auditory membranes, especially the membrana tympani or drum, is regulated with the utmost nicety by the tensor tympani, laxator tympani, and stapedius muscles, which are so arranged that they move the malleus, incus, and stapes in a backward and forward direction upon thin articulations, and so repeat the vibrations which enter the ear.

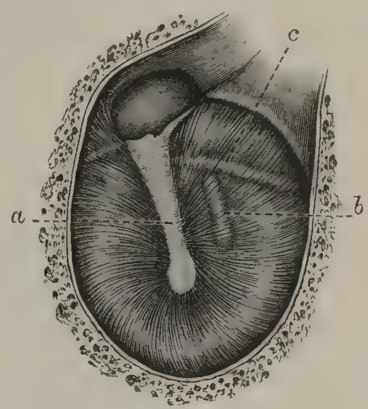

Fig. 227.—Shows left *membrana tympani* or drum of ear as seen from the outer ear after removal of the cutaneous layer, considerably magnified. *a*, Handle of *malleus* seen behind drum of ear; *b*, long process of *incus* shining through drum; *c*, reflection of *chorda tympani* nerve, which crosses drum of ear behind (after Schäfer).

(*e*) The labyrinth or internal ear, situated on the inside of the membrane of the foramen ovale. "This consists of a complicated cavity excavated in the petrous portion of the temporal bone, and comprising an ovoid central portion (the vestibule or porch), a double spiral canal (the cochlea), and three semicircular canals, all communicating by means of the common vestibule. All parts of this cavity contain a watery fluid termed the *perilymph*. The vestibule and semicircular canals also contain closed membranous sacs, suspended in the fluid of the perilymph, which reproduce exactly the form of the bony cavities themselves, and communicate with each other in a similar way. These sacs are filled with another watery fluid, the *endolymph*; and the terminal filaments of the auditory nerves are distributed upon the membranous sac of the vestibule and upon the ampullæ or membranous dilatations at the commencement of the three semicircular canals. The remaining portion of the auditory nerve is distributed upon the septum between the two spiral canals of the cochlea."[1]

It will be evident from the foregoing that the essential part of the auditory apparatus is the *internal ear*; the other parts being merely accessory.

The internal ear may be defined as a cavity, partly membranous and partly bony, occupying the petrous portion of the temporal bone, this cavity being supplied with certain membranes on which the ultimate filaments of the auditory nerve ramify; these membranes being bathed from without and within by fluids (perilymph and endolymph). The auditory nerves alone are capable of appreciating sonorous impressions.

The accessory parts are :—

(*a*) The auditory meatus and external ear, which collects the sonorous vibrations from the atmosphere.

(*b*) The membrana tympani or drum of the ear, which receives and transmits the sonorous vibrations.

(*c*) The chain of small bones (malleus, incus, and stapes), which communicate with the membrane covering the foramen ovale.

The process by which sound is produced and appreciated is as under :—The sounding body is itself thrown into vibration, the vibration spreads in waves to the surrounding air, the air waves collected by the concha or funnel-shaped portion of the external ear penetrate the external auditory meatus or passage and impinge against the membrana tympani or drum of the ear, which being thrown into vibration causes the malleus, incus, and stapes to move backwards and forwards. The rocking of these bones, in turn, produces vibration of the membrane covering the foramen ovale, which being in contact with the fluids contained in the internal ear causes them to surge in waves and impinge against the terminal filaments of the auditory nerve distributed to the membranous parts of the labyrinth. The sound waves travel by an indirect and circuitous route to the filaments by the auditory nerves, and the sensation of sound is ultimately due to a fluid impact. The trunks of the auditory nerves convey the sensation of sound to the brain.

[1] "A Treatise on Human Physiology," by John C. Dalton, M.D., Professor of Physiology, &c. Philadelphia, 1871, p. 521.

The arrangement of the parts composing the membrana tympani or drum of the ear is of the utmost importance in normal hearing. The drum must be healthy, and the bones connected with its inner surface in a condition to vibrate freely, and so convey the sound waves to the outer surface of the membrane covering the foramen ovale, which membrane communicates them to the membranous part of the labyrinth, nerves, and fluids of the internal ear. In order that the drum may vibrate freely and fairly, the air on either side of it must be unconfined and of nearly the same temperature. These conditions are secured by the drum being placed towards the centre of a through canal, the outer portion of which is formed by the external auditory meatus or passage ; the inner portion by the middle ear, and Eustachian tube which opens into the pharynx.

The precise degree of tension in the drum is, in every instance, secured by the action of the tensor tympani and stapedius muscles. The object in view is so to stretch the membrana tympani or drum that the number of vibrations made by it in any given time shall exactly correspond with the number of vibrations communicated to it by the waves of sound in the external air : in other words, to ensure that the drum and the surrounding air shall sound the same note at the same instant. The tightening of the drum enables it to register, interpret, and appreciate the higher notes ; the relaxing of the drum fits it for dealing with the lower notes.

If the drum be too taut, it fails to recognise and register low notes ; if it be too lax, it fails to recognise and register high notes. The rapidity with which the drum requires to be strung up or tuned to recognise and register all the notes which the human ear is capable of hearing is simply astounding. The tuning of a harp with its numerous strings, difficult as it admittedly is, is the veriest child's-play. In listening to a piece of concerted music the drum has to be tuned to every note heard ; the pitch of each note being determined by the number of vibrations in a given time. The analysis of musical notes by the drum is one of the most rapid and subtle known. It bespeaks a degree of perfection and adaptation difficult to realise. It brings out in a striking manner the absurdity of the theory which requires a separate stimulus for every muscular act, the aggregate of which stimuli extending over illimitable time ultimately formed the drum and other parts of the ear.

The ear by means of the drum accommodates itself to sounds in precisely the same manner as the eye accommodates itself to distance. In order to hear a sound perfectly, and in order to enjoy the sound fully, the drum must be strung up to an extraordinary degree of nicety. In order to appreciate harmony without there must be harmony within. This is one of those extraordinary adaptations of means to ends which fill the mind with admiration and wonder. It has been thought by some that sound may be transmitted through the bones of the head, and so reach the brain. There are good grounds for believing this to be a mistake. Where a special apparatus is provided nature employs it. The highway for sound is that indicated, namely, the external auditory meatus or external ear, the middle ear, and the internal ear, with the natural outlet formed by the Eustachian tube. We do not expect light to enter the body by any other route than by the eye, and similar remarks may be made of sound and the ear. Indeed we have direct proof of this. If the fingers be placed tightly in the ears all external sounds are immediately cut off. If any sound enters, it is indirectly by the Eustachian tube, and this explains why we can hear ourselves talk when the ears are stopped. The cranial bones are incapable of communicating vibrations to the labyrinth and its contents unless very faintly and imperfectly.

§ 240. Internal Ear or Labyrinth.

The external and middle ear are comparatively simple, and consequently not difficult to understand. It is otherwise with the internal ear or labyrinth. This, as its name implies, is very complicated, and requires to be carefully described. The labyrinth in reality forms the essential part of the acoustic organ. It consists of three portions, namely, the vestibule, the semicircular canals, and the cochlea. These form a series of cavities in the petrous portion of the temporal bone which communicate externally with the cavity of the middle ear through the fenestra ovalis and fenestra rotunda, and internally with the meatus auditorius internus, which contains the auditory nerve.

Within the osseous labyrinth is contained the membranous labyrinth upon which the ramifications of the auditory nerve are distributed.

The vestibule, as its name implies, is the common central cavity of communication between the parts of the internal ear. It is placed on the inner side of the middle ear, behind the cochlea and in front of the semicircular canals.

The semicircular canals are three bony canals situated above and behind the vestibule. They describe the greater part of a circle, are compressed from side to side, and are of unequal length. They measure about the twentieth of an inch in diameter, and are dilated to about twice this size when they enter the vestibule. The expanded portions are known as the *ampullæ*. Two of the canals are nearly vertical in direction, the other is horizontal.

The cochlea in its general contour resembles the shell of a snail, and hence its name. It forms the anterior part of the labyrinth, is conical in shape, and placed almost horizontally in front of the vestibule. Its base is perforated by numerous apertures for the passage of the cochlear branch of the auditory nerve. It consists of a conical-shaped central axis, the modiolus, or columella ; of a canal wound spirally round the axis for two and a half turns ; and of a delicate lamina (the lamina spiralis), which divides the spiral canal into two parts, the one called the scala vestibuli, the other the scala tympani. The lamina spiralis divides towards its peripheral margin to form the scala media. The original spiral canal of the cochlea is consequently subdivided into three smaller ones, the scala vestibuli, scala media, and scala tympani ; scala meaning a passage. The lamina spiralis is the essential part of the cochlea, it being that on which the ultimate filaments of the auditory nerve are distributed. It consists of two thin laminæ of bone, between which are numerous canals for the passage of nervous filaments, which open chiefly on the lower tympanic surface. The cochlea measures about a quarter of an inch in length, its breadth at the base being the same.

The scalæ or passages into which the spiral canal is subdivided communicate with each other at the apex of the cochlea—the lamina spiralis being deficient in the last half coil of the canal. The spiral canal, it will be seen, communicates directly with the vestibule and indirectly with the middle ear, and the different parts of the canal communicate with each other.

The inner surface of the osseous labyrinth is lined by an exceedingly thin fibro-serous membrane resembling periosteum, which secretes a clear watery fluid known as perilymph.

The membranous labyrinth consists of a closed membranous sac having the same general form as the vestibule and semicircular canals in which it is enclosed. It contains a clear serous fluid, the endolymph, and is separated from the lining membrane of the vestibule and semicircular canals by another clear serous fluid, the perilymph. The membranous labyrinth affords the basis of support for the ultimate filaments of the auditory nerve in the semicircular canals. The vestibular portion of the membranous labyrinth is divided into the utricle and saccule, the former being a little larger than the latter.

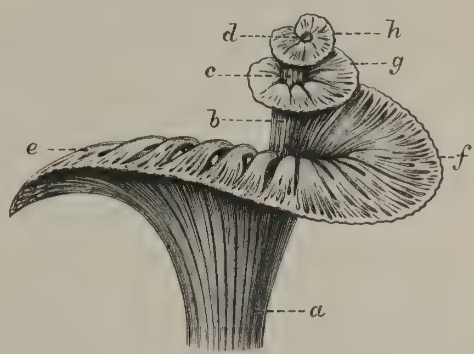

FIG. 228.—Shows the general view of the mode of distribution of the cochlear nerve, all the other parts having been removed ; magnified ten times. *a, b, c, d,* Strands of cochlear nerve successively bending over to be distributed in the several parts of the *lamina spiralis* (*e, f, g, h*) of the cochlea (after Arnold).

In the wall of the utricle and saccule, opposite the area of distribution of the auditory nerve, are small rounded bodies, the otoliths, composed of a mass of minute crystalline grains of carbonate of lime held together in a mesh of delicate fibrous tissue. A calcareous material is also, according to Bowman, sparingly scattered in the cells lining the ampulla of each semicircular canal. These cretaceous substances act as sonorous bodies, and increase the power of the sound waves as they beat against the delicate terminal filaments of the auditory nerve.

This nerve, on which the sense of hearing depends, divides at the bottom of the internal auditory meatus into two branches, the cochlear and vestibular, and the trunk and branches contain numerous ganglionic cells with caudate prolongations.

"The cochlear nerve divides into numerous filaments at the base of the modiolus, which ascend along its canals, and then, bending outwards at right angles, pass between the plates of the bony lamina spiralis close to its tympanic surface (Fig. 228). Between the plates of the spiral lamina, the nerves form a plexus, which contains ganglion cells ; and from the margin of the osseous zone branches from this plexus are distributed to the membranous part of the septum, where they are arranged in small conical-shaped bundles, parallel with one another "[1] (Plate cxxxix., Figs. 3 and 4, p. 762).

The vestibular nerve divides into three branches, the superior, middle, and inferior.

The superior vestibular branch is distributed to the utricle and the ampulla of the external and superior semicircular canals ; the middle one to the saccule ; and the inferior to the ampulla of the posterior semicircular canal.

In the utricle and saccule the nerve fibres spread out, some blending with the calcareous matter, others radiating on the inner surface of the wall of each cavity, becoming blended with a layer of nucleated cells, and terminating in a thin fibrous film.

As already explained, the internal ear or labyrinth consists of an osseous and a membranous part, the membranous part being bathed within and without by fluid (endolymph and perilymph), and having embedded in its substance the terminal filaments of the auditory nerves and certain calcareous substances known as otoliths. It follows from this that the fluids, otoliths, and auditory nerve expansions are all in contact. This arrangement greatly facili-

[1] "Anatomy, Descriptive and Surgical," by Henry Gray, F.R.S., Lecturer on Anatomy at St. George's Hospital, London. 1858, p. 581.

tates the perception of sound, a sonorous impulse communicated from without throwing the fluids of the internal ear into waves, these surging and causing the otoliths and other calcareous particles to impinge against each other and against the ultimate expansions of the auditory nerve. The commotion thus produced in the otoliths and other calcareous particles is aptly compared by Huxley to that produced by the pelting of the showers of little stones and sand on a gravelly beach which are raised and let fall by each wavelet of the advancing tide, and which produce a definite impression on the nerves of the skin while bathing. The membrane on which the ends of the auditory nerves are spread out, he observes, is virtually a sensitive beach, and waves, which by themselves would not be felt, may be readily perceived if they suffice to raise and let fall hard particles. The cretaceous bodies found in the membranous labyrinth may occur either as minute calcareous sand or as hair-like filaments which arrange themselves at right angles to the membrane.

The epithelium (and this is a remarkable circumstance), which covers the termination of the nerves in the ampulla, is provided with long, stiff, hair-like processes, which are made to vibrate the instant the endolymph is made to move. In the vestibular sac these hairs are scanty or absent, but the minute angular otoliths serve the same purpose.

Huxley remarks : "It is very clear that the vibrations, or waves of sound, reaching the ear from some sounding body, in passing along the endolymph, set in movement these hairs, very much as waves of the wind set in movement stalks of standing corn, and that the movement of the hairs, by help of the cells to which the hairs belong, excites the delicate filaments of the nervous network below, and so sets up disturbances or impulses which pass along the auditory nerve to the brain." [1]

Here the physical nature of the impact made upon the terminal filaments of the auditory nerves by sonorous bodies through air waves, waves of fluid, otoliths, calcareous hairs, &c., is established beyond a doubt. There is no mystery as to the *modus operandi*. The calcareous hairs may be likened to finger ends feeling the vibrations produced by sounding bodies, and transmitting them straight to the brain by means of the auditory nerves. Similar finger-like processes (the rods and cones) occur at the posterior surface of the retina of the eye. These deal with the waves of luminous ether, and are described further on.

In addition to the otoliths and calcareous hairs referred to, there are other important structures connected with hearing to which it is necessary to direct attention.

In the scala media of the cochlea minute rod-like bodies are found, which are apparently extensions and refinements of the calcareous hairs. They are peculiarly modified cells of the epithelial lining of the scala, and are known as the fibres of Corti.

The precise function discharged by the vestibular nerve spread out on the membranous labyrinth, and that discharged by the cochlear nerve spread out on the lamina spiralis, is not yet thoroughly made out.

Experiment goes to show that the vestibular nerve and membranous labyrinth enable us to determine the intensity and quantity, but not the quality of sound ; the cochlear nerve and lamina spiralis enabling us to determine the quality and modulation of sound, apart from its intensity and quantity. The modern belief is that every possible sound is represented by the vibration of a separate filament of the cochlear nerve, and that an educated musical ear by means of these filaments can not only appreciate individual notes but also the chords or groups of notes which form concerted harmony.

The scala media is said to resemble the keyboard of a pianoforte in function and appearance ; the fibres of Corti being the keys—the ends of the nerves representing the strings which the keys strike. This view seems proved by the following simple experiment. If two tuning-forks having the same pitch be employed, and the prongs of one of them be struck and made to vibrate, the prongs of the tuning-fork struck communicate its vibrations to the surrounding air ; the air-waves in turn throw the prongs of the other tuning-fork into vibration. The two tuning-forks and the air vibrate, throb, or pulsate at precisely the same rate of speed, and the two tuning-forks sound in unison and give out the same note. The note emitted by the tuning-fork thrown into vibration by the air-waves is a repetition of the note first emitted, and in full sympathy with it. The same result is often produced accidentally. For example, a note is struck on the pianoforte or some other musical instrument in a room, and something in the room vibrates in unison and repeats the note. This is known as sympathetic vibration.

Supposing, therefore, we compare the rods of Corti to so many tuning-forks, it is evident that each particular note would operate by means of the perilymph upon that tuning-fork or Cortian rod whose vibrations are in unison with its own, the other tuning-forks or Cortian rods being absolutely or relatively unaffected. As, however, each Cortian rod is set in full vibration by a particular kind of wave sent through the perilymph, and no other, and as, moreover, each Cortian rod affects only one filament of the cochlear nerve, we arrive at the belief that the filaments of the cochlear nerve are differentiated and modified to appreciate every variety and form of sound.

The scala media and its Cortian fibres and nerves, so far as known at present, are the instruments by which

[1] "Lessons on Elementary Physiology," by Thomas H. Huxley, LL.D., F.R.S. London, 1885, p. 221.

we are enabled to perceive external harmony. If these parts become diseased, musical delusions are produced, hence singing in the ears, and other sounds so common in temporary deafness.

It is often a very difficult matter to determine the direction of sound. It is impossible to tell what part of a closed chamber a cricket occupies, although it chirps without ceasing. The same difficulty is experienced out of doors. It is very difficult to say where a bell is rung in a fog. Here, however, the direction of the wind and a knowledge of locality assist us. We turn the head round, and ascertain whether the sound strikes the right or left ear, and judge accordingly. The condition of the atmosphere also assists. The atmosphere must be always taken into account in judging of sound.

Sonorous impulses cannot be produced *in vacuo*, or where there is no matter to throw into vibration. If the sonorous impulses or undulations are less than sixteen to the second they are perceived as so many distinct or isolated raps; if they are more than sixteen to the second they blend and fuse to form a continuous note.

The sense of sound is less ethereal in its nature than that of sight. The impressions which produce it are more akin to those which produce general sensibility. Thus we can speak of sharp, dull, sweet, smooth, or rough sounds. The explosion of a great gun affects the drum of the ear very much as a blow affects any other part of the body. In man the organ of sound attains to marvellous perfection. An educated musical ear is permitted to luxuriate in quite a wealth of sound, and it is quite remarkable to what an extent the ear may be educated. I have known individuals who were positively pained by a false note or chord. Others, again, as the phrase goes, have no ear. In them music is the least disagreeable of all noises.

The sense of sound, like the other senses, becomes accustomed to certain impressions, and after a time ceases to recognise them. Thus any one accustomed to sleep in the vicinity of a waterwheel awakes if the water is shut off and the wheel ceases to move.

Sounds live in the imagination when the sonorous body has ceased to vibrate. We take the keynote from a tuning-fork, and remember it when the fork is laid aside.

§ 241. The Sense of Sight—The Structure of the Eye, &c.

The parts more especially concerned in sight (Plate cxli., p. 765) are the corpora quadrigemina, the optic nerves, and the expansions thereof, namely, the retinæ. The eyes are accessory but indispensable structures. The tubercula quadrigemina, otherwise called the optic ganglia, are situated on the base of the brain posteriorly, and consist of four small rounded masses or ganglia which preside over the sense of sight. They have a crossed action, and are very important, from the fact that they give origin to the optic nerves, and are intimately connected with the function of seeing. If they are broken up with needles or destroyed by disease the sense of sight is at once and permanently destroyed.

Section of the optic nerves is followed by a like disastrous result. The tubercula quadrigemina are much developed where the eyes are large, as in fishes, reptiles, and birds. They are comparatively small in quadrupeds and in man. They are supposed to act as reflex centres, to regulate the size of the pupil or apertures of the iris, and to regulate the quantity of light admitted into the eyes. There are grounds for believing that the so-called reflex action of the corpora quadrigemina in connection with the function of the iris is not well founded. I will discuss the subject further on, when I come to speak of the structure and movements of the iris itself.

The optic nerves extend between the tubercula quadrigemina and the retinæ, and consist of rounded bundles of white nerve fibres. The optic nerves, or "*tracts*," as they are sometimes called, are to be regarded as nerve commissures—

(*a*) Because they extend between the optic tubercles (tubercula quadrigemina), which contain grey matter, and the retinæ, which consist mostly of vesicular or cellular nervous matter; and

(*b*) Because in man they connect the tubercles and retinæ directly and indirectly with each other. Thus the fibres of the optic nerves have a crossed action, and pass from the right and left tubercles to the left and right retinæ; some passing from the right tubercle to the right eye and from the left tubercle to the left eye; others connecting the right and left tubercles and the right and left retinæ together.

The optic nerves convey the special impression of light to the brain. According to Longet they are insensitive throughout their entire length. If the retinæ or optic nerves be artificially stimulated, luminous sparks or flashes of light are produced, but no pain is experienced. Division of the optic nerves results in complete blindness. This operation does not produce insensibility in any part of the eye; neither does it cause muscular paralysis.

A blow on the eye produces a shower of sparks which, if once seen, is rarely forgotten. This effect is most probably produced by direct and sudden compression of the eyeball, the compression forcing the fluid contents of the eye directly against the retina, and so producing a direct impact. Normally the light (which is a form of

motion) impinges against the retina so softly and gently that we are apt to think that no impact is produced by it. To get rid of this idea it is only necessary to remember that the eyeball consists of solid, semi-solid, and fluid parts, and that an impulse communicated to the solid parts transmits the impulse to the fluid parts, and that the fluid parts are in contact with, and, under the circumstances, impinge against the retina. The eye is surrounded by matter in an extremely minute state of division. If that matter be thrown into energetic undulations the eye perceives it as light; if the undulations be less energetic, as twilight.

Sight occupies the first rank in the special senses. It is the gateway which admits the greatest quantity of information. The sight is at once the most refined and subtle of all the senses. It has, moreover, to deal with the most subtle impressions. In order to taste a body, the body in a soluble form must impinge against the peripheral expansions of the gustatory nerves. The contact of the tasted with the tasting body is obvious and palpable.

In order to smell a body, the body of emanations from it must impinge against the peripheral expansions of the olfactory nerves. The contact between the smelling organ and the odoriferous substance is less obvious. As, however, matter occupies all space, it is immaterial whether the smelling substance directly assails the nose, or whether it does so indirectly by the innumerable particles which it gives off, and which float in the air and are taken into the nostrils in the act of breathing.

Similar remarks are to be made of sight. The luminous body may be an immeasurable distance from the eye. It may be the sun, the moon, or any of the fixed stars. Still, as light is a form of motion and all space is filled with matter, it follows, as a necessary consequence, that the ethereal particles set in motion by the luminous body react upon each other in endless succession until the surface of the eye is reached. An impact received here is transmitted in an antero-posterior direction through the solid, semi-solid, and fluid parts of the eye to the retina, and by this conveyed through the optic nerves to the optic tubercles (tubercula quadrigemina), where it is perceived by the brain. In sight we appear to be dealing with the immaterial. This, however, is more a fancy than a fact. Do what we may, we cannot escape from matter.

In order to appreciate the immeasurably delicate impacts produced by light, the eye is differentiated and modified to quite a remarkable extent. The impacts referred to are not made directly upon the retina or peripheral expansions of the optic nerve alone, but upon the conjunctiva, cornea, aqueous humour, hyaloid membrane, lens, vitreous humour, &c. The retina is, as it were, placed within the inner sanctuary of the eye, and no light reaches this until it has been measured by the pupil, and diffused and softened by the crystalline lens, and by the aqueous and vitreous humours. The retina receives its impressions, impulses, or impacts indirectly through a solid, semi-solid, and aqueous medium. In order to see clearly, the exquisitely delicate retina must be bathed and kept moist by a fluid, and this holds true also of the external parts of the eye.

The eye is adapted for receiving luminous impressions either through the atmosphere or through water.

The eyes adapted for water are less sensitive than those adapted for air. The eyes of the morse (walrus), sea-lion, and other marine animals are tawny in colour, and usually much congested. They want the bright transparency which characterises the eyes of the gazelle. This is probably due to their coming in contact with salt water, as the eyes of the frog, which are bathed by fresh water only, are remarkably clear.

Having spoken of the nature of the impressions conveyed to the eye, it is now necessary to describe the apparatus by which they are transmitted to the retinæ and optic nerves, and how they are perceived by the brain.

Proceeding from before backwards the parts of the eye encountered are the following: (*a*) the conjunctiva; (*b*) the cornea; (*c*) the aqueous humour; (*d*) the iris; (*e*) the hyaline membrane or the anterior capsule of the crystalline lens; (*f*) the crystalline lens itself; (*g*) the posterior portion of the capsule; (*h*) the vitreous humour; (*i*) the hyaline membrane covering the retina; (*j*) the retina itself; (*k*) the optic nerve; (*l*) the optic tubercles (tubercula quadrigemina). On the outside, and behind the retina, are the choroid and sclerotic coats. To these are to be added the eyelids and eyelashes, the lachrymal glands, and the muscles moving the eyeballs. Here is quite a bewildering multiplicity of hard and soft parts, but they are all necessary to the production of perfect sight.

It will suffice if I say a few words regarding each in the order stated, and dilate slightly on the more important.

The conjunctiva is a delicate, highly sensitive membrane which covers the anterior surface of the eyeball.

The cornea is a watch-shaped, fibrous structure immediately behind the conjunctiva, which projects forward and forms the front of the eye. It is a continuation of the sclerotic or strong fibrous coat which gives roundness and shape to the eyeball and affords support to all the delicate tissues and fluids forming the eye.

The aqueous humour is a clear, slightly alkaline fluid which comes between the cornea and the iris, and between the iris and the crystalline lens. It occupies the anterior and posterior chambers of the eye, and fills up what would otherwise be empty cavities.

The iris is a highly important musculo-vascular structure suspended between the cornea and the crystalline lens. It is a continuation of the choroid or vascular coat of the eyeball, and forms the coloured portion of the

eye. Posteriorly it is covered by a layer of dark-coloured pigment. Literally it means a rainbow. It consists of a circular screen with an aperture or hole in the centre called the pupil, and is largely engaged in keeping the internal soft parts (aqueous and vitreous humours) of the eye in position. It is composed of radiating and circular muscular fibres, which endow it with characteristic centrifugal and centripetal movements, these movements being more or less rhythmical in their nature. It is a living, highly sensitive structure, expressly formed to regulate the amount of light admitted into the interior of the eye. When there is much light, or a strong light, it diminishes its aperture by a centripetal movement, and when there is little light, or a feeble light, it increases its aperture by a centrifugal movement. The size of the aperture or pupil is directly under control.

The iris affords an example of a piece of mechanism specially prepared to perform a definite function. The movements of the iris are said to be due to reflex action caused by the operation of light on the one hand, and the influence exerted by the corpora quadrigemina on the other. Thus the impulse produced by the light is said to be transmitted through the optic nerves to the optic tubercles and the brain, and reflected outwards by the oculo-motorius nerve to the ophthalmic ganglion, and so through the ciliary nerves to the iris.

This so-called reflex theory does not account for the facts. The muscles of the iris, for example, act apart from light altogether. In sleep, for instance, when the eyelids are closed, the pupil is contracted. It is also contracted in opium poisoning. It is dilated in coma from compression of the brain. It is also dilated in viewing remote objects. It is contracted and dilated by mental emotions, and powerfully contributes to the expression of the eyes. According to the reflex theory the varying degrees of light falling upon the eye occasion the several muscular movements of the iris. The light—the dead thing—is made to control the living thing. The same cause, so to speak, is made to produce diametrically opposite results; to enlarge the aperture or pupil of the iris the one instant, and partially to close it the next. Here the living thing is ignored in favour of the dead thing (light); a mechanical is substituted for a vital act. The iris, as stated, is a living, highly sensitive, muscular apparatus, the sole function of which is to increase and diminish the size of its central aperture or pupil at intervals, according to the strength of the light falling on the eye at the time. Its movements are expressly arranged to regulate the amount of light admitted into the eye—in other words, to control the light; yet, according to the reflex theory, the iris, instead of controlling the light, is controlled and set in motion by the light. The effect is substituted for the cause. Inasmuch as the light is always present during the day and waking hours, it is difficult, or indeed impossible, to explain how its continued presence can account for what are practically interrupted, rhythmic, and opposite movements in the iris. The only way out of the difficulty, it appears to me, is to credit the iris with inherent, independent powers, similar to those conferred on the heart, stomach, bladder, uterus, &c., which enable it to open and close, or partially close, as those viscera do.

The movements of the iris are associated, co-ordinated movements for a purpose and to a given end. In this sense they are fundamental. While they are original movements analogous to those of the heart or chest, they are to some extent due to training and constant repetition, which give them the appearance of automatic movements.

Any one who watches a child training its eyes in various lights, or an aged individual focussing his eyes and glasses in an uncertain light, or under emotion, will be convinced that the movements of the iris are not reflex in the ordinary sense. Similar remarks may be made regarding the so-called reflex winking movements. These are also interrupted or rhythmic in their nature, and occur only during the waking hours and when there is light. Their function is to spread the tears over the eyeball at constantly recurring intervals, and to keep the conjunctiva and cornea moist and transparent. The want of moisture in the eye of the dead subject renders the eye opaque like ground glass.

The crystalline lens of the eye is situated behind the iris. It projects into the aqueous fluid in front and the vitreous humour behind. As its name indicates, it is a pellucid, clear substance. It is a transparent, double convex body, the convexity of which is greater on the posterior than on the anterior surface. It consists of concentric layers of fibrous tissue, which increase in density from within outwards. Its function is to produce distinct perception of form and outline. If the eye consisted merely of a sensitive retina covered by a transparent integument, the retina would perceive the light, but would fail to perceive the form of the objects which the light revealed.

The vitreous humour is a clear, thin, semi-fluid, albuminous substance, contained in a delicate hyaline membrane. It fills the cavity of the eye between the posterior surface of the crystalline lens and the anterior surface of the retina or expanded portion of the optic nerve. It distends the eyeball, keeps the crystalline lens and retina in a transparent condition, and acts, within limits, as a fluid lens.

Quite the most important structure in the eye is the retina. This consists of the terminal filaments of the optic nerve mixed up with numerous delicate vessels. The two together form a nervo-vascular expansion which assumes the shape of a spheroidal sac, the open mouth of which is directed forwards, and terminates at the posterior margin of the ciliary body.

Outside and behind the retina is the choroid coat, a vascular membrane rendered opaque by a layer of blackish-

brown pigment, the function of which is to absorb the light which has passed through the retina and so prevent its being reflected in such a manner as to confuse or dazzle the sight. The iris, as stated, is a continuation and modification of the choroid coat.

The retina is bathed anteriorly by the vitreous humour, a gelatinous, albuminoid substance of a spheroidal form. It is surrounded and retained in position by a thin, structureless membrane—the hyaloid membrane. This membrane invests the anterior surface of the retina, and the anterior and posterior surfaces of the crystalline lens. It, in fact, forms the capsule of the lens.

The muscles which move the eyeball are attached to the outside of the sclerotic coat, which, as explained, forms the external envelope of the eye.

They are so arranged that they can turn the cornea, or front of the eye, in any direction. The eyelids afford protection to the eye; they also provide for the due distribution of the tears over the surface of the cornea, which is by this means kept perfectly transparent. After death, and when tears cease to be produced, the eye becomes glazed and dim.

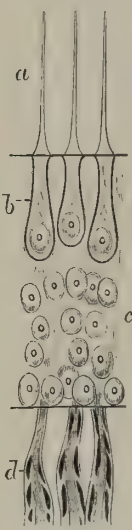

Fig. 229.—Section of epithelium of ampulla of *Lacerta viridis*. Showing auditory vibratile hairs, hair cells, medullated nerve fibres, &c. *a*, Auditory hairs; *b*, hair cells; *c*, nuclei of supporting cells; *d*, medullated nerve fibres. Magnified (after G. Retzius).

The organ of vision is supplied with nerves of ordinary sensibility by the ophthalmic division of the fifth pair. These are distributed for the most part to the conjunctiva, the lachrymal gland, and the skin of the eyelids, a few of them being distributed to the ciliary circle and iris. The ophthalmic ganglion supplies the ciliary nerves distributed to the iris and ciliary muscle. The muscles which move the eyeballs derive their motor nerves from the third, fourth, sixth, and seventh pairs.

The important function performed by the retina in the production of sight necessitates a careful description of that structure.

The optic nerve enters the back of the globe of the eye, not in the middle, but one-tenth of an inch or so on the inner or nasal side of the centre. It then spreads out on the inner surface of the wall of the globe to form the retina, which varies in thickness from the eightieth of an inch to less than half that amount. The retina appears as a membrane of great delicacy and of a uniform smooth texture, unless at the central point of the posterior wall, where it presents a slight circular depression of a yellowish hue, known as the *macula lutea* or yellow spot. A little nearer the nose is a characteristic radiating appearance produced by the entrance of the optic nerve and the diverging of its fibres to form the retina.

If a thin section of the retina (the yellow spot and the entrance of the optic nerve excepted) be made, and placed under a microscope, the following structures may be seen proceeding in a direction from before backwards (see Plate cxli., Fig. 11, p. 765, and compare with analogous auditory structures shown in Fig. 10 of the same plate, and also with Fig. 229):—

(*a*) A delicate stratum of fibres from the optic nerve.

(*b*) A layer of ganglionic corpuscles continuous with convoluted nerve fibres, and probably with the stratum of fibres from the optic nerve.

(*c*) A layer of convoluted fine nervous fibres.

(*d*) The inner granular layer, composed of fibres in which granules are imbedded.

(*e*) A close meshwork of very delicate nervous fibres, from which the fibres of the inner granular layer are given off.

(*f*) The outer granular layer, composed of very delicate fibres which proceed from the anterior extremities of the rods and cones, in each of which a granule-like body is developed.

(*g*) The layer of rods and cones occurring on the posterior surface of the retina. This layer forms nearly a fourth of the entire thickness of the retina, and consists of a vast multitude of minute rod-like and conical bodies ranged side by side perpendicularly to the plane of the retina.

Mixed up with what may be regarded as the essential or nervous structures of the retina are certain connective tissues which constitute a framework for them. Enumerated from before backwards they are:—

(*a*) The anterior limiting membrane of the retina in contact with the vitreous humour of the eye.

(*b*) The molecular layer.

(*c*) The inter-granular layer.

(*d*) A layer of nuclei.

(*e*) The radial fibres passing to the internal or anterior limiting membrane.

(*f*) The external or posterior limiting membrane.

The connective tissue or framework stops short at the rods and cones, these not being supported by it. The nerve fibres and blood-vessels are also placed in front of the rods and cones. The rods and cones are, in fact, left free to vibrate, and to detect and appreciate the most delicate impacts on the part of the air or ether.

At the entrance of the optic nerve itself the nervous fibres predominate, and the rods and cones are absent. This part of the eye is blind. In the yellow spot, on the other hand, the cones are abundant and close set and increased in length, the rods being scanty, and occurring only towards its margin. Here vision is most acute. In the centre of the yellow spot (*macula lutea*) the layer of fibres of the optic nerve disappears, all the other layers (the cones excepted) becoming extremely thin.

The distinguishing feature of the retina, as explained, is its power of converting the vibrations of ether which form the physical basis of light into what is believed by many to be a stimulus to the fibres of the optic nerve; these fibres, when excited, having the power of awakening the sensation of light in the brain.

Huxley remarks "that the sensation of light is the work of the brain, not of the retina; for if an eye be destroyed, pinching, galvanising or otherwise irritating the optic nerve will still excite the sensation of light, because it throws the fibres of the optic nerve into activity; and this activity, however produced, brings about in the brain certain changes which give rise to the sensation of light. Light falling on the optic nerve does not excite it; the fibres of the optic nerve in themselves are as blind as any other part of the body. But just as the delicate filaments of the ampullæ, or the octoconia of the vestibular sac, or the Cortian fibres of the cochlea of the ear, are contrivances for converting the delicate vibrations of the perilymph and endolymph into impulses which can excite the auditory nerves, so the structures in the retina appear to be adapted to convert the infinitely more delicate pulses of the luminiferous ether into stimuli of the fibres of the optic nerve." [1]

The sensitiveness of the several parts of the retina to light varies very materially; the point of entrance of the optic nerve being absolutely blind, the yellow spot having the most acute vision. The impression made by light on the retina remains for a short time after the light is gone. (This is also true of taste and smell.) Thus if we gaze at the sun for some time, and suddenly dart into a dark room, the luminous image remains, it is estimated, for the eighth of a second or so.

A rotatory disc with a luminous point in it gives a circle of flame if the movement be sufficiently rapid. If we emerge suddenly from a brilliantly lighted hall into outer darkness we must wait until the luminous images disappear before we can proceed with safety.

The sensitiveness of any part of the retina is easily exhausted. Thus if a bright light falls upon the eye, and we suddenly turn away from it and look in another direction, we perceive a dark spot; this corresponding to a blind spot temporarily produced by the bright light.

If the bright light be coloured, the dark spot assumes a complementary colour. Thus if the retina be fatigued by a bright red colour, the dark spot appears green, and so of the other complementary colours.

The presence of light is not necessary to produce a sensation of light. Thus an electric shock passed through the eye produces a flash of light. Pressure upon the eyeball does the same. It is difficult to say whether the retina or optic nerve is acted upon in such cases.

It is a remarkable circumstance that the fibres of the optic nerve which ramify on the anterior fourth of the thickness of the retina are insensible to light; the rods and cones which occupy its posterior fourth being alone affected by it.

This is proved by the fact that the blind spot *is full of nervous fibres* but is destitute of rods and cones; whereas the yellow spot, where the most acute vision is situated, *is full of close-set cones*, but has no nerve fibres.

It would appear that the cones and rods which occupy the posterior fourth of the retina, and have their extremities turned towards the light, are to be regarded as so many finger-points of a sufficiently delicate organisation not only to feel the luminous vibrations but also to distinguish their intensity and colour.

Not the least interesting feature of the retina is its shape. As already stated, it forms a spheroidal membranous bag. This peculiar form enables it to detect the direction from which the rays of light proceed, and the situation and form of the luminous body. Thus the rays which enter the pupil from below reach the retina only at its upper part, whereas those which come in from above reach it at its lower part. In both instances the rays strike the sensitive surfaces perpendicularly, and so convey the impression of their direction, whether from above or from below. The retina by itself would not form a perfect organ of vision. It requires the aid of several accessory structures, the chief of which is the crystalline lens.

The crystalline lens is, as previously stated, a transparent, double convex body, the convexity of which is greater on the posterior than the anterior surface. Its function is to produce distinct perception of form and

[1] "Elementary Lessons in Physiology," by Thomas H. Huxley, LL.D., F.R.S. London, 1885, p. 246.

outline. If the eye consisted merely of a sensitive retina, covered by a transparent integument, the retina would perceive the light but would fail to perceive the form of the objects which the light revealed.

This admits of easy demonstration. If a luminous body, say an arrow placed vertically with its tip up, be presented to an eye not provided with a double convex lens, the rays of light diverge from every part of the arrow and reach every part of the retina. The different parts of the arrow are mixed up and confused (Plate cxlii., p. 766).

This confusion is at once got rid of, and a clear image of the arrow obtained, by introducing a bi-convex lens between the arrow and the retina. By this arrangement all the rays proceeding from the tip of the arrow, which is uppermost, are concentrated and focussed at a corresponding but inverted point on the lower border of the retina ; those emanating from the butt of the arrow, which is directed downwards, being in like manner concentrated and focussed at a corresponding inverted point on the upper border of the retina. A clear image of the tip and butt of the arrow involves a clear image of all the parts of the arrow between the tip and the butt. The only peculiarity is that the arrow is inverted on the retina. All other objects presented to the retina are also inverted.

The convergence or focussing of the rays of light is accomplished principally, but not solely, by the crystalline lens. The other transparent and refracting parts of the eyeball assist.

Distinctness of vision depends on a variety of circumstances, such as the density of the crystalline lens, the curvature of its surfaces, and its distance from the retina. If the lens be too convex and its refractive power excessive, or its distance from the retina too great, the rays converge and focus too soon, and do not reach the retina until they have crossed each other and become partially dispersed, producing confusion of vision.

If, again, the lens be too flat, or placed too near the retina, the rays do not converge at all, but strike the retina separately, and so produce a confused image as before.

In both cases the cause of the confusion is the same ; the rays which come from one point of the object strike the retina at different points. In the first case the rays converge and diverge before reaching the retina ; in the second case the rays reach the retina before they converge or focus. In either case the rays reach the retina in a straggling, confused manner. These peculiarities are corrected by employing spectacles consisting of variously shaped artificial lenses.

One of the most peculiar, and, at the same time, most important properties of the eye is the power it possesses of accommodating itself to different distances. A healthy eye can see an object clearly at the distance of a foot or of one or more miles.

In order to do this the eye must adapt itself to the altered conditions, for it is quite evident that if the rays of light from an object converged and gave a distinct impression of it at a short distance, they would, if no change were effected in the refractive parts, cross and give a confused image at a long distance.

This is proved by a very simple experiment. If we take two stakes and fix them in the ground in nearly the same line, the one at the distance of a yard from the eye, the other at a distance of thirty yards, we find that we cannot see the two stakes clearly at one and the same time. Thus if we close one eye, and focus the other to see the near stake clearly, the distant stake becomes blurred. If on the other hand we focus the eye to see the distant stake plainly, the near stake becomes blurred. It is impossible, therefore, to see near and distant objects distinctly at the same instant. The eye must accommodate itself to distance.

Various theories have been propounded to explain the manner in which this accommodation is effected. Some suppose that it is due to a change in the curvature of the cornea ; others to a change in the curvature of the crystalline lens ; others to an antero-posterior movement of the lens, by which its distance from the retina is increased or diminished ; others to a change in the figure of the entire eyeball, whereby its longitudinal axis is elongated or shortened. Others attribute the power of accommodation to the action of the ciliary muscles. We have here five distinct theories. The favourite one is that which presupposes a change in the curvature of the crystalline lens.

Any of the other theories would equally account for the power of accommodation possessed by the eye.

That which advocates an antero-posterior movement of the lens recommends itself by its simplicity, and the same may be said of the theory which presupposes a change in the long axis of the eye.

However produced, the power of accommodation possessed by the eye is undoubted. The power is exerted voluntarily. It is exerted more for short than for long distances. The eye is in a great measure at rest when directed into space. It is only when we come to examine an object carefully at a short distance that we are conscious of changing the focus of our eyes. Under these circumstances the eye becomes fatigued.

While the eye can adjust itself to see clearly at long distances, even to the fixed stars, it is impossible for a healthy eye to adapt itself to see an object plainly at a distance of less than six inches or thereabouts. This is traceable to the want of focussing power for short distances.

As all the light which enters the eye must pass through the pupil or circular aperture in the iris, it follows that there is in front of the eye a certain space within which luminous objects are perceived by the retina, and beyond which they cannot be seen. This is known as the circle of vision. The space in question is described as circular because the rays coming from the side or from behind cannot enter the pupil.

For short distances there is only one point in the centre of the circle of vision at which objects can be seen distinctly.

The perfection of the eye as the organ of sight depends, to a certain extent, on the iris. This, as stated, is furnished with an aperture in its centre (the pupil), by which the precise amount of light required in each particular case is admitted. If there be too much light, the iris contracts and diminishes the pupil; if too little, it dilates and increases the pupil.

In order to determine distance and form, the two eyes must work together. This follows because the two eyes are placed in the head at a certain distance from each other, and when a single object is looked at their axis must meet at the point of sight. The point of sight is nearer or more remote according to the distance of the object. If the object looked at be near, the axes of the two eyes are necessarily very convergent, and the angle which they form with each other is a large one; if the object be remote, the axes are more nearly parallel, and the angle is less. Thus if we look at a landscape we cannot see the foreground, middle distance, and distance distinctly at one and the same time. If we contemplate the foreground, the middle distance is obscure, the distance still more so. The details of the landscape diminish in proportion to distance. In fact, what we call distance is neither more nor less than a gradual dwarfing or obscuration of the elements composing the landscape.

The combined action of the two eyes is also very valuable for near objects in giving us an idea of *solidity* or *projection;* for within a certain distance the visual axes, when directed together at a solid object, are so convergent that the two eyes do not receive the same image. This is the case when we look with the two eyes at any solid object in our immediate vicinity. The right eye sees partly round one corner, the left eye seeing partly round the other. Advantage is taken of this circumstance in producing stereoscopic effects.

It will be seen from my observations on the sense organs and their mode of working that the higher animals and man are specially endowed, and that when highly elaborated sense organs exist they are to be regarded as specially created instruments and adjuncts of the conscious ego or self. The sense organs in the highest animals, and their counterparts in the lowest animals and in plants, are the gracious gifts of an all-bountiful and beneficent Creator. Nothing is withheld from living animals and plants which can contribute to their well-being.

No plant and no animal is forgotten in the comprehensive and all-wise scheme of the Almighty. The lowest plants and animals up to man are guaranteed life and a certain measure of enjoyment.

Everything that lives is supplied with air, light, heat, moisture, food, &c., and each organism is provided with a something which enables it to perceive (dimly, it may be) a world outside of itself.

What that something is in plants and the lowest animals, we cannot at present determine. It may be a sensitive protoplasm, or a diffuse nervous system; but whatever it is, it is guaranteed to all.

We have seen that many plants, such as the sundew, Venus's flytrap, and other sensitive plants, feel, and feel acutely. We have also seen that the lowest animal organisms, such as the amœba and *Gromia*, also feel. We have further seen that feeling differs less in kind than in degree, and that while everything that lives feels, the highest animals, as a rule, feel the most—that is, experience the greatest number of sensations. This they do because of the greater number of sense organs possessed by them, as compared with the lowest animals.

The senses in the higher animals are always associated with a nervous system, and it may be taken for granted that in proportion as the nervous system becomes elaborated, so the sense organs increase in number and in complexity.

It is the nervous system which more especially connects the higher animals with the planet they inhabit. It does this through the senses of touch, taste, smelling, hearing, and seeing.

The nervous system, as I have explained, seeks the surface of the body in a variety of ways :—

(*a*) As nerves of general sensibility distributed to every part of the body;

(*b*) As nerves of special sense distributed to the head—as, for example, the nerves of taste distributed to the tongue; the nerves of smell distributed to the nose; the nerves of hearing distributed to the ear; and the nerves of seeing distributed to the eye.

The higher animals, by the aid of their numerous and complex sense organs, realise the world they live in in divers ways. They can touch, taste, smell, hear, and see it; nay more, they can see other planets in the infinity of space.

The object of the senses is to adapt the higher animals to their surroundings—to enable them to know and to feel their place in nature. In order to do this the senses must be situated on the surface of the body, or at

that point where the body touches external nature. The brain, which is the great sense emporium, must throw itself outwards by means of nerves of general sensibility and nerves of special sensibility. The nerves of general sensibility seek the skin, the nerves of special sensibility the several sense organs. The nervous system, especially the sense organs, may be fitly represented by vibratile, finger-like processes (rods and cones, &c., of eye and ear).

The sense organs enable the nervous system (or rather the brain, which is the highest representative of nerve substance) to feel, taste, smell, hear, and see the matter by which it is invested in every direction. They are to the brain what the fingers are to the body. They grope about in space at near and remote distances.

The sensitive nerves in the feet are touched by the ground; the nerves in the tongue are touched by the food we eat; the nerves in the nose are touched by smelling matter floating in the atmosphere; the nerves of the ear are touched by the waves of sound generated by sounding bodies; and the nerves of the eye are touched by the waves of light emanating from the sun and other luminous bodies. There is nothing mysterious in the sense organs. The highest and the lowest of them are mere *touch organs*, and all of them must come in contact with extraneous matter before they can discharge the functions delegated to them. To comprehend the nature of the sense organs we have always to bear in mind that they are material in their nature, and that they are connected with matter centrally and peripherally; with brain matter on the one hand, and with the matter of external nature on the other. The sense organs are sensitive feelers of various degrees of refinement, but all transmit to the brain a knowledge of external objects. Each sense organ is adjusted with marvellous exactitude to perform certain work. In the senses, the grand doctrine of the division of labour is conspicuously displayed. Light falls in vain upon the skin—it is the duty of the eye to inform the brain that light is present.

Sound does not affect the nose—the ear must announce to the brain the presence of a sounding body; a sapid substance is not appreciated by the eye or the ear—it remains for the tongue to apprise the brain that a savoury morsel is in its vicinity; a smelling body is not detected either by the skin, the tongue, the ear, or the eye—it is the prerogative of the nose to communicate this intelligence to the brain.

It is easy to conceive a being with a greater number of sense organs, and those of a more exalted character than we behold in man, and such a being would possess a more extended knowledge of external nature than we do. The eye might be microscopic or telescopic as to its powers, and the ear might be telephonic or phonographic. We might have additional senses to enable us to detect the presence of electricity and other phenomena which we do not recognise at present.

The senses may be taken as the limit of capacity as far as the power of appreciating external nature goes.

The eye of the eagle can pierce space to a greater distance than the eye of man, the nose of the dog can detect scents for long distances where man's olfactory nerves are useless, and the ear of the deer enables it to detect sounds not appreciable by human ears.

This shows two things—

(*a*) That the senses are relative gifts, and always keep pace with the requirements of the individual; and

(*b*) That the senses might be improved and increased in number.

There is something very consoling in the belief that everything which lives, feels. Feeling in a healthy organism is synonymous with enjoyment. When the plant turns its leaves to the light, and the lower animal forms seek the heat and the sunshine, it is plain that they luxuriate in both.

The amount of enjoyment obtained from the senses may be taken as the measure of our loss when the senses are impaired or destroyed. As a rule we are not sufficiently grateful for the innumerable benefits conferred upon us by the healthy action of the sense organs.

A blind man is the best judge of the value of sight, and a deaf man, more than any other, places a high value on the sense of hearing.

A deaf child necessarily grows into a dumb man. He is cut off for ever from those delightful sounds which gladden the ear; from the familiar and tender tones of the human voice; from the swelling harmony of the minster with its jubilant hallelujahs; from the voice of nature, which appeals to man in a thousand different ways. The blind child is equally to be pitied. As a man he can derive no enjoyment from the tender daylight, revealing as it does the gorgeous landscape, resplendent with rock, river, sea, and sky; neither can he behold the glorious orb of day, nor the pale moon surrounded by innumerable golden stars.

The child whose sense of smell is absent can never inhale the steaming incense of the newly upturned earth, nor the delicate aroma distilled from a million sweet-smelling flowers; in like manner the child whose sense of taste is vitiated can never enjoy to the full the savoury morsels which nature in her plenitude has so bountifully supplied to the whetted appetite of youth.

It goes without saying that a man deprived of his sense organs would be debased to a very low level in the scale of being, and would, if left to himself, inevitably perish. The deprivation of even one of the senses is always

a great calamity, but where two or more are absent the individual, as a rule, is no longer able to maintain his place in society and in nature.

The senses of hearing and seeing are the most missed.

The senses improve by use and by education. Over use and abuse bring stern retribution. The eye and ear may not be overtaxed and overstrained with impunity. If the nose be habitually assailed by strong, irritating fumes it loses its power of detecting and appreciating delicate odours ; if the tongue and palate become accustomed to highly spiced foods and strong drinks, a time comes when the primitive flavour of things disappears.

The capacity for enjoyment very largely depends on the integrity of the sense organs, and this furnishes an unanswerable argument for their use as against their abuse. The argument is one in favour of moderation and temperance. A knowledge of the sense organs and their mode of working is calculated profoundly to impress every thinking and every sane man. The sense organs, perhaps more than any other things in living organisms, reveal adaptation and means to ends. In them the Creator at once reveals His marvellous power and His boundless beneficence.

THE PHONOGRAPH AND TELEPHONE IN THEIR RELATIONS TO THE HUMAN VOICE AND EAR, AND AS ILLUSTRATING THE INTIMATE CONNECTIONS WHICH SUBSIST BETWEEN THE INORGANIC AND ORGANIC KINGDOMS

It would be difficult, if not indeed impossible, to find more perfect examples of design, law, order, and complemental interaction and co-ordination than are afforded by the human voice and ear on the one hand, and the phonograph and telephone on the other (see Plates cxliii., cxliv., pp. 863, 866). The organ of voice is the most marvellous of all sound-producing instruments, and the human ear is the most delicate interpreter or appreciator of sound known. The human voice and ear have much in common ; they are constructed on essentially the same principle. They are both dependent on vibrations in the air ; the one (the voice) produces air vibrations or sound waves ; the other (the ear) receives air vibrations or sound waves, and transmits them to the brain directly or indirectly. The organ of voice is one of the Creator's choicest gifts to man, and enables him to commune with his fellow-beings in joy and in sorrow, and to an extent which it is difficult to realise. The ear, on the other hand, enables him to appreciate mirth-moving hilarity and human sympathy, and to interpret the various moods of those with whom he comes in contact ; to revel in sweet musical sounds ; and to flee when harsh and other sounds indicate danger.

The organs of voice and hearing are complementary structures, and are extremely complicated both as regards their mechanism and their mode of working. They are to be regarded as original endowments conferred on men and animals at birth as part of their fundamental equipment for their comfort and guidance. They make their appearance during the embryonic stages of development, and, in the higher animals, are gradually perfected during gestation and soon after parturition, when they are required. They are, in the main, developed before they are required, and cannot, strictly speaking, be regarded as the products either of evolution, natural selection, or irritability.

While the organs of voice and hearing are not confined to man, it is in him they attain their highest value and utility. Most animals make signs to each other, but in none can such advantage be taken of the voice and ear as in man. The spoken word is peculiar to him, and his inventions of the phonograph and telephone enable him to reproduce the voice at his own fireside or several hundreds of miles away. The organs of voice and hearing and the phonograph and telephone afford extraordinary instances of design, of means to ends, and of law and order in things living and dead. They show that the same principles obtain in the organic and in the inorganic kingdoms, and that similar laws regulate both. They also show that action and reaction have virtually the same range in both kingdoms, and that the interactions between these kingdoms are of the most intimate and far-reaching character.

In order fully to realise what is meant by the phonograph and telephone in their relations to the human voice and ear, it is necessary to say a few words regarding Matter and Force as they exist in the universe, and the sense organs in ourselves, by the aid of which we are enabled to recognise and appreciate them.

Matter and force in the universe are now known to be fixed quantities—that is, they neither admit of increase nor diminution.

To man is granted the power (and it is a god-like power) of transforming matter and force.

Man may change the form of matter. He can cause it to assume various shapes : he can remove it from one

place to another on the earth's surface, and, in this sense, it is subservient to him, and he can use it for his own purposes without let or hindrance. He cannot, however, increase or diminish it; he can neither create nor destroy matter.

In like manner, he can change the direction of force. He can cause it to act in straight lines, in circles, obliquely, and even at right angles.

He can harness the lightning, and utilise the rushing torrent and cascade in performing all kinds of work. These are natural forces, and they are placed unconditionally in the hands of man, and he is lord over them as he is lord over matter. He cannot, however (and mark this), create force; neither can he add to, or take from, its quantity.

Matter and force, as explained, are constant quantities in the universe, and therefore indestructible.

To take examples. I could manipulate clay or wax and make a bust, and could subsequently break the bust; but the clay and wax, or the atoms composing them, would remain. This is merely the transformation of matter. Similarly, I could place a water-wheel in a swiftly flowing stream and drive the machinery of any kind of mill. The energy of the flowing water could be transferred to the axle of the water-wheel, and become the motor or power for driving the mill. This, it will be seen, is a mere transposition or transformation of energy.

Nature gives to man a bountiful supply of matter and force, but in trust only, and for temporary purposes; she gives nothing to him absolutely, and when the proper time arrives, like Shylock, she relentlessly claims her pound of flesh.

From what has been stated, it will be evident that man *creates* nothing. It is important to bear this in mind, as the so-called discoveries and inventions of man are only examples (magnificent ones, certainly) of intellectual sagacity in interpreting and utilising the works and forces of nature. Even the steam generator or boiler, and the steam-engine, in all their parts, pre-exist in nature.

The extraordinary wisdom of Solomon is at its best when he says, "There is no new thing under the sun" (Ecclesiastes i. 9).

It is the intellectual mastery of man over the matter and force of the universe which has enabled him to construct the phonograph, the telephone, the telegraph, the microphone, and other delicate instruments, and to show their relations to the human voice and ear.

In the long history of the world (and the world is not young) there are no finer examples of action and reaction between the outer world and man than are furnished by the instruments in question. They could only be constructed by physicists and physiologists having the most profound knowledge of matter and force as they exist in the universe, and of matter and force as they exist in man.

It is necessary in this connection to refer briefly to the nature of matter and of force in the outer world and in ourselves, as I cannot otherwise show the interaction which is constantly going on between them, and how they are complemental and co-ordinated.

Matter in the universe may be roughly divided into three kinds, namely, solids, fluids, and gases.

They are all composed of atoms or particles, the only difference being that in the solid matter the particles are packed closely together, whereas in fluids and gases they are more or less widely separated—the particles in gases being separated to quite a remarkable extent.

For my present purpose, matter in the universe may be divided into earth, water, and air.

These are outside of ourselves, but they are also within ourselves. Our bodies contain comparatively little solid or earthy matter; over 70 per cent. is water; air and gases circulate freely within us. We are constantly taking in and giving out all three. There is no distinction between the matter found outside and within ourselves, and this fully explains the extraordinary sympathy which subsists between man and the universe, and how the organic and inorganic kingdoms react upon each other.

The forces in nature are spoken of as the *physical* forces, and are supplied by the sun, the lightning, ordinary fire, the tides, running streams and waterfalls, the winds, chemical changes on a vast scale, &c.

The forces within ourselves are called *vital* forces, and consist of nerve energy (mental and otherwise), muscular force (voluntary and involuntary), secreting and operating force, organic chemical force, vito-mechanical force, &c., as they are exemplified *in living, organised matter*.

Some physicists and physiologists maintain that all force, whether it be found in the outer world or in ourselves, is physical in its nature. This is only partly true. It is true to the extent that matter and force are inseparable, and in building up our bodies from the matter of the universe we of necessity transfer, with the matter, the force which naturally resides or inheres in it. Vital force has, however, a separate existence, and is superior to physical force.

It is safe to assert, that in ourselves force is in part *vital*, and in part *physical*, and for this reason. In living

organisms (plant and animal), the vital forces can override and direct the physical forces. Indeed the prerogative of life is, that it can utilise, neutralise, or re-direct any of the physical forces as such, and can select and assimilate, or reject and extrude, whatever matter it pleases.

Seeing there is such an intimate relation between the matter of the universe and the matter in our own bodies, the question naturally arises, How is man adapted to his surroundings ?—how, in other words, is he geared to, or connected with, the universe ?

I reply, By the sense organs ; these constitute the five gateways of knowledge, and through them all the information he possesses of the outer world is obtained.

Man is covered by a sensitive skin, which enables him to feel when he is touched by anything *outside of himself*. The skin gives him a knowledge of things in his immediate vicinity, which actually come in contact with him.

He is furnished with a taste organ which enables him to realise the presence of sapid substances when placed in his mouth. The sapid substances touch him. He is provided with an organ of smell which enables him to detect minute odoriferous particles in the air. These particles also touch him. He is granted ears which permit him to appreciate the presence of sounding bodies, near or remote. These bodies touch him indirectly. Lastly, he is furnished with eyes which enable him to peer into space and discern bodies at immeasurably great distances. Here, again, there is indirect contact.

It is with the organ of the ear and the vocal chords we have more especially to deal on the present occasion. We have also to deal with the substances inside and outside the body which produce and transmit sound.

The substances in the body which produce the greatest variety of sound are the vocal chords. These, by their vibrations, originate the voice.

The substances in the body which receive and transmit sound to the brain are those forming the outer ear ; the membrana tympani or drum of the ear ; the ossicles and air in the middle ear ; the membrane of the fenestra ovalis or inner drum ; and the fluids, otoliths, and hairs in the inner ear.

In the outer world every substance which can be made to vibrate produces sound, and the transmitter of sound between the sounding body and the ear is, in the majority of cases, the atmosphere or air.

I have now to consider very briefly the nature of sound, and of the air as the transmitter of sound.

Sound can be produced in an infinite number of ways ; by the explosion of a big gun, the stroke of the woodman's axe, the ringing of a bell, the beating of a drum, the vibrating of a tuning-fork, the twitching of a fiddle-string, the movements of the vocal chords in the human larynx, &c. (Fig. 1, Plate cxliii., p. 863).

Sound in every instance is the result of a body being made to vibrate in space, and the number of vibrations in the sounding body, per second, determines the pitch of the sound. If the vibrations are fewer than 16 to the second, a series of separate raps are heard ; if more than 16 to the second, the separate raps merge into each other and produce a rough, more or less continuous sound or note. Professor Helmholtz estimated that from 28 to 30 vibrations per second were required to form a musical note. The note C on the added line is the outcome of 256 vibrations a second (Fig. 3, Plate cxliii.).

As regards the transmission of sound to the ear, this, as a rule, is effected by the aid of the air, which is thrown into waves by sounding bodies (Fig. 2, Plate cxliii.).

The air, when still, can neither be seen nor felt. It is, nevertheless, material in its character. It is only when made to move violently as in a hurricane, or when struck very rapidly by a flat surface, that its material nature becomes apparent. The cyclone and tornado can uproot the strongest trees and overturn the most substantially built houses. The wings of the bird, say of the pigeon, as I discovered in 1873,[1] can, because of the tremendous energy with which they strike it, elicit a click from the air, and a recoil which forces the bird upwards and onwards. The material nature of the air alone makes these results possible.

The rationale of sound production and hearing is briefly as follows :—

A body is made to vibrate in space, say a bell, or the end of a drum ; the substances of the bell and drum are surrounded by, and are necessarily in contact with, the air. The moment the vibration begins, the air is thrown into waves—the so-called sound waves—and these are produced by the alternate compression and rarefaction of the air. The best illustration I can give of air waves is that furnished by analogy. If a stone be thrown into a still pool of water it will be observed that from the point of contact of the stone with the water a series of concentric rings or waves proceed ; the rings or waves becoming larger, and their strength less, as the original point of contact is receded from.

Precisely the same thing happens when a sounding body agitates the air. In this case the sounding body takes

[1] "Animal Locomotion," 1873.

the place of the stone. The waves, as before, spread in concentric rings—in this case in all directions—the sound waves losing force in proportion to their distance from the sounding body. This explains why sounds become more faint in the distance, and why, consequently, they are more difficult to hear.

That the air is necessary to the transmission of sound is proved by this, that a bell rung in a vacuum, or a space in which no air is present, cannot be heard. Curiously enough, the air, or rather the particles which it contains, are necessary also to the transmission of light. Professor Tyndall proved this by smearing the interior of a glass box with glycerine. In the course of a few days the motes floating in the air settled on, and were trapped by, the glycerine, with the result that the air within the box was purified. When he directed a ray of light in a dark room against the box, with its air so purified, the ray ceased to be visible within the box.

Sound travels at various degrees of speed, according to the media through which it passes. Thus in air it travels at the rate of 1093 feet per second when the temperature of the air is at the freezing-point of water.

The velocity increases with the temperature a little more than one foot for every degree Fahrenheit, so that at 60° the velocity is 1125 feet per second.

In water the velocity with which sound travels is about four times greater than in air; in pine wood about ten times, and in steel sixteen times.

Great as are these velocities, they are as nothing compared with the speed at which electricity travels—electricity, as will be shown presently, being one of the forces employed in the construction of the modern telephone.

High tension electricity, such as the spark from a Leyden jar, attains a velocity of over 200,000 miles per second; low tension electricity, as developed from a battery, travels only at the rate of 15,000 or 20,000 miles per second; but this is very largely a matter of conductors. Its velocity is seldom above 30,000 miles per second on ordinary telegraphic lines.

The latter (30,000 miles per second) is no mean speed. It is such as practically to annihilate time and space. It means 1,800,000 miles per minute. Mr. Wheatstone proved, a good many years ago, that the duration of the electric spark was less than one millionth of a second. When a swiftly moving body can be seen by an electric spark, or flash of lightning, it looks as if it were quiescent. This follows because in the short time during which the body is illuminated it does not appreciably move. No attempt has apparently been made to measure the velocity of magnetism. If, however, it be a form of motion in ether, Professor Dolbear thinks it probable that the velocity is comparable to the velocity of radiant energy and light—that is, about 186,000 miles per second.

It may be well if, in this connection, I say a word or two regarding the nature of electricity, as it leads up to remarks I shall have to make presently regarding the telephone.

Electricity, like heat and light, is a form of motion. Its production necessitates the presence of matter. It requires material conductors, and cannot be made to pass through a vacuum.

That it is a form of motion seems to be proved by the following considerations:—

1st. It can itself produce *motion*. It deflects the needle of a galvanometer.

2nd. It can directly produce *heat*. Electricity can burn a platinum wire.

3rd. It can directly produce *light*. This is seen in every spark given off by an electric machine, in the lightning flash, and in the electric light now in common use.

4th. It can produce magnetism. A current of electricity passing through a coil of copper wire converts a bar of soft iron placed within the coil into a magnet. It becomes the familiar *electro-magnet* employed in the construction of the telephone in daily use. If, instead of the bar of soft iron, one of hardened steel be employed, the latter becomes a *permanent magnet*.

The mode of production of electricity also favours the view that it is a form of motion.

It may be produced simply by friction, that is, by the vigorous rubbing of a great variety of substances such as stones, gums, a large number of resins, sealing-wax, sulphur, amber, and so on. These substances, with their surfaces so excited, will attract light bodies, such as feathers, strips of linen, &c. Some of them—for instance, sulphur—if vigorously rubbed with a dry hand in a dark room, will give out light, accompanied by a peculiar hissing or crackling sound.

Electricity may also be produced by *chemical action*. Thus if two metals, say zinc and copper, or copper and silver, be placed in a vessel or cell and exposed to the action of dilute sulphuric acid, a very good current of electricity is at once generated. This lasts until the plates of metal exposed become polarised.

Fig. 4, Plate cxliii., p. 863, gives a good idea of the action going on in the battery cell when the metals employed are platinum and zinc, and the fluid hydrochloric acid.

The platinum and zinc plates, as a reference to the figure in question shows, are connected in the air by a

wire at the top; they are connected below by the molecules of hydrochloric acid. As soon as the arrangement is completed the chemical action begins, and electricity is produced, and flows in the direction indicated by the darts. The action is accompanied by a hissing sound, bubbles of hydrogen gas being seen to rise from the platinum plate. At the same time the zinc plate begins to dissolve and form chloride of zinc.

Other and analogous batteries have been made by Daniell, Grove, and Bunsen.

Electricity may be produced by the contact of different metals. Thus if silver and iron, or bismuth and antimony, be soldered together at one end, and the other end be connected with a galvanometer, it is found that on heating the soldered ends of the metals a current of electricity traverses the circuit. When different metals are thus soldered in series they form the so-called *thermo-pile.*

Electricity is also produced by the action of magnets. This is known as *magneto-electricity,* and is that more especially employed in the telephone.

To understand what is meant by magneto-electricity it is necessary to understand what is meant by a magnet.

The magnet or lodestone is one of the iron ores, and is furnished ready made by nature.

If a slab of lodestone be placed among iron filings it is seen that they adhere in greatest quantity upon two opposite ends or sides, which are named the poles of the lodestone or magnet. If, moreover, it be suspended by a strand of untwisted silk so as to permit it to turn freely, it will invariably come to rest with the same pole directed towards the north—this being the north pole of the magnet.

The natural magnet can transfer by contact its peculiar and very remarkable properties to a bar of steel or even of soft iron.

A needle of steel magnetised by contact with a magnet forms, when suspended by a delicate silken fibre or hair, the mariner's compass.

If a natural or artificial magnet be made to pass within a coil or helix of copper wire, which is connected with a galvanometer, a current of electricity is produced. If, conversely, a current of electricity be made to flow through the coil of wire, and a soft iron bar be placed within the coil, the soft iron is converted into a magnet, and is called an *electro-magnet,* which, as already stated, is that more particularly employed in telephony.

The first electric magnet was made by winding bare copper wire round the soft iron, and was weak.

When, however, the wire was insulated by covering it with silk, a very powerful magnet was produced.

The power of the electro-magnet is enormously greater than that of any permanent magnet. Dr. Joule made an electro-magnet capable of supporting 3500 times its own weight.

The quantity of magnetism that can be induced or temporarily conveyed to a soft iron bar is almost unlimited, depending as it does upon the size and strength of the magnet, and the length of wire in the coil.

There are many forms of machines for developing electricity from the action of coils of wire in front of the poles of permanent magnets.

They are known as *magneto-electric machines,* and have an important bearing on the telephone. They are illustrated at Fig. 5, Plate cxliii., p. 863. In this figure, which is taken from Professor Dolbear's work on the "Telephone," n, s represent the permanent magnet, which is bent into a U form to utilise both poles. n', s' are short rods of soft iron (not magnetised) fastened into a yoke-piece y, also of soft iron. Coils of copper wire surround each of the rods, the ends of the wires connecting with each other and with what is called a pole changer; the whole of this part is capable of revolving upon an axis y, p, by the pulley at p.

The action is as follows. "From the position of the soft iron rods, n', s' must be magnets through the inductive action of the permanent magnet n, s. So long as the parts have the relative position shown in the figure, and there is no motion, no electricity can be developed;[1] but if the axis p, y be turned, s', which represents the polarity of the rod opposite n, will be losing its induced magnetism; and when half a revolution has been made that same pole will be where n' now is; but it will then have n' polarity instead of s', that is, it has been losing south polarity as it receded from n and gaining north polarity as it approached s; hence a current of electricity has steadily been flowing through the coil in one direction. At the same time the other rod, n', has passed through similar phases, and its enveloping coil has had a current of electricity induced in it in the same direction as in the first coil.

"This doubles the intensity of the current; and the whole is conducted by the connecting wires where the current is wanted. Machines have been built on this plan that contained fifty or sixty powerful compound, permanent magnets, and as many wire coils, requiring a steam-engine of 8 or 10 horse-power to run them."[2]

[1] "In this respect we are reminded of the behaviour of the soft iron within the coil, which gives origin to a current of electricity when it is made to approach a magnet or recede from it, but gives no current so long as it is still." ("The Telephone," &c., by Dolbear, p. 33.)

[2] "The Telephone: an Account of the Phenomena of Electricity, Magnetism, and Sound," by Professor A. E. Dolbear. London, 1878, pp. 31 and 32.

Having briefly explained the nature and behaviour of inorganic and organic substances; their interdependence and convertibility; their adaptability to each other; the material nature of the atmosphere and of sound; the peculiarities of magnetism and electricity, and of the voice and ear, we are now in a position to discuss the structure and uses of the phonograph and telephone.

The telephone was devised before the phonograph, but as the phonograph is, in some respects, the simpler instrument, it will be convenient to begin with it; the more especially as it will afford me an opportunity of explaining, more or less fully, the anatomy and physiology of the human voice and ear.

§ 242. The Structure and Working of the Phonograph.[1]

The phonograph, as its name indicates, is an instrument devised for recording or writing down the human voice. It was originally the discovery of Mr. T. A. Edison. The term "phonograph" is derived from the two Greek words, *φωνή*, the sound of the voice, and *γράφω*, to grave or write (Plate cxliii., Fig. 14).

The instrument is one of the latest outcomes of modern science, and a marvel in its way. Not only does it write down or record the human voice; it also writes down and preserves the peculiar intonations and quality of the voice. Further, and still more important, the writing is practically indelible. A speech delivered by a famous orator, or a solo sung by a celebrated prima donna to-day, may be re-spoken or re-sung by the instrument to-morrow, or at an interval of a century or of many thousands of years. Verily, the dead yet speaketh after the most literal fashion.

The phonograph is, to say the least, a mysterious little instrument—especially mysterious and awe-inspiring to the uneducated and superstitious. All mystery, however, disappears on a careful examination of its structure, and a knowledge of the conditions under which it operates.

In explaining the construction of the phonograph, it is necessary to refer in a general way to the properties of the atmosphere, and to the anatomy and physiology of the vocal chords and of the human ear. The phonograph, the atmosphere, the vocal chords, and the ear, are to be considered together—the phonograph as the recorder of sound, the atmosphere as the transmitter of sound, the vocal chords as the producers of sound, and the ear as the recipient or hearer of sound.

These four are substantial entities. The phonograph, as an instrument, is composed of parts, *material parts;* the atmosphere is composed of particles, *material particles;* the human voice is the result of the vibration of the vocal chords, *material chords;* and the human ear is composed of many substances, *all material* in their nature. We are thus dealing with matter, and the physics of matter.

The parts entering into the composition of the phonograph are the following:—

(*a*) A screw cylinder with a screw axle, the thread of the screw on the surface of the cylinder being the exact counterpart of that on the axle.

(*b*) A solid framework with two vertical supports, one of which is provided with a screw nut, which causes the cylinder, when made to rotate by the hand, clockwork, or other motor, to move from right to left, or from left to right.

(*c*) A sheet of tin-foil, carefully applied by the aid of mucilage to the screw surface of the cylinder. (Recently a layer of wax has been substituted for the tin-foil.)

(*d*) A movable funnel-shaped structure, corresponding to the mouth and external ear, for giving off to, and collecting sound waves from, the atmosphere. This structure, by the aid of thumbscrews, can be made to approach to or recede from the cylinder, and move in a lateral direction.

(*e*) A thin vibrating disc, corresponding to the *membrana tympani*, or drum of the ear, placed on the end of the funnel-shaped structure.

(*f*) A delicate needle, corresponding to the chain of bones in the middle ear, the root of which is fixed to the centre of the vibrating disc; its point, when the funnel-shaped structure is in position, being in contact with the tin foil on the revolving cylinder. As the needle advances and retires every time the vibrating disc moves, it pricks or indents the tin-foil between the ridges of the screw surface of the cylinder to different depths, according to the intensity of the vibrations of the disc; the intensity of the vibrations of the disc being regulated by the intensity of the sounds or sound waves produced by the voice. To prevent the needle always pricking the tin-foil in the same place, the cylinder bearing the tin-foil is made to move at a uniform speed from right to left. By this means the structure of the tin-foil is preserved, and confusion in the pricking prevented.

[1] My "Observations on the Phonograph, or Speech Recorder in its Relations to the Human Voice and Ear," were originally published in *Modern Thought*, February 1882.

So much for the mechanism of the phonograph. Now for a word regarding the *modus operandi*, or the manner in which it works.

When the voice is to be written down, the operator or speaker places his mouth in the funnel-shaped portion of the instrument, and says what he has to say in a clear, articulate manner (Fig. 230). The voice agitates or throws the air into waves, *material* waves, and these impinge upon and agitate the vibrating disc, and cause it and the needle affixed to it to move backwards and forwards at a variable speed, and at variable degrees of force, according to the modulations of the voice, and the number, force, and intensity of the air-waves.

At the time when the funnel-shaped portion of the instrument is receiving the spoken words, and transmitting them by means of its vibrating disc and needle to the tin-foil on the cylinder, this latter (the cylinder) is made to move steadily from right to left, by means of its screw, actuated, as stated, by the hand or other motor; the pricks or indentations made by the needle of the vibrating disc being thus separated from each other.

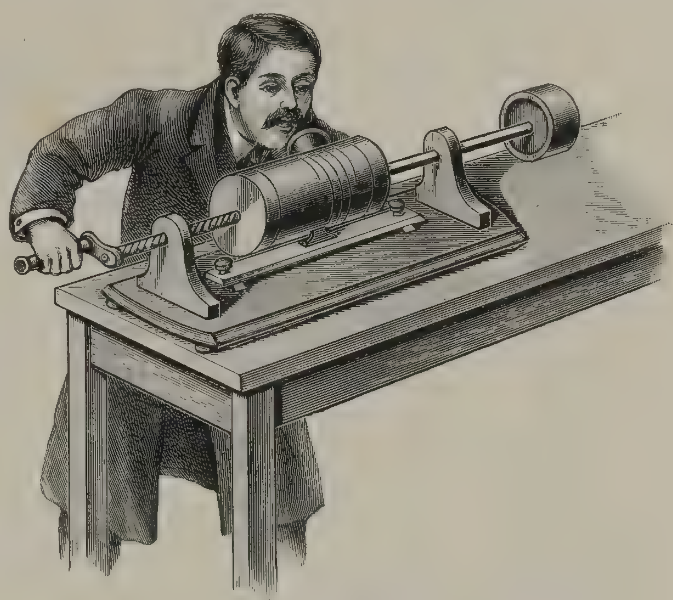

Fig. 230.—Phonograph.

When the words spoken are pricked into the tin-foil on the cylinder, the needle fixed to the vibrating disc is temporarily withdrawn from the surface of the cylinder, and the cylinder made to travel from left to right, or back to the place from which it originally started—that is, the place it occupied before the speaking commenced. This done, the needle is again placed in position, and the cylinder made to rotate from right to left by means of its screw, actuated as before. As a matter of course, the needle, during the second excursion of the cylinder, goes into every prick or indentation originally made by it, with the result that it throws the disc into which it is fixed into vibration, the disc in turn throwing the atmosphere with which it is in contact into vibration; the atmospheric waves in due time issuing from the funnel-shaped portion of the instrument and assailing the drum of the ear, and causing it to vibrate, with the marvellous result that the human voice is reproduced and heard by us in its totality, with its ever-varying intonations, and with all its wonderful pathos, tenderness, and power.

Human song, the melody of an instrument, and, indeed, every audible sound, is recorded in precisely the same manner. The funnel-shaped portion of the phonograph is, at once, the mouth and the ear of the instrument. It collects the vibrations of the vocal chords or voice in the first instance, and distributes them to the ear in the second instance.

When it is intended to preserve the word spoken, or the melody sung, all that is necessary is to preserve the tin-foil with its labyrinth of indentations, and the instrument or its counterpart by the aid of which the indentations were originally produced. Given the indented tin-foil, and the instrument, the human voice may be reproduced at any interval of time, however remote.

How vastly interesting it would be to unborn generations to transmit in their entirety and wonderful fulness the beautiful voice of Jenny Lind, or that of the silver-tongued Gladstone! and how gratifying and instructive it would be to the present generation to listen to the soul-stirring philippics of Demosthenes and Cicero, or the philosophic utterances of Plato, Socrates, and Aristotle!

The phonograph is as yet a comparatively imperfect instrument, but it has doubtless a great future before it, and the time may come when by its aid, and the aid of similar inventions, the word spoken may become not only the word written, but the word printed, in which case the errors of reporters and compositors will be effectually prevented.

The phonograph, there is reason to believe, will become more and more perfect in proportion to the advances made in physics, and acoustics, a branch of physics.

It combines in its construction, as already indicated, the organ of voice and the organ of hearing, its vibrating disc closely corresponding to the vibrating vocal chords placed within the larynx, and the vibrating *membrana tympani*, or drum placed within the ear. It receives the waves of sound, the so-called sonorous waves, and it reproduces them. It thus discharges a double function, in so far that it will either receive impressions (in the shape

PLATE CXLIII

Plate cxliii. illustrates the production of sound, sound waves, musical notation, electric induction, electric battery, electro-magnet, the phonograph or speech-recorder, the telephone or speech-transmitter, &c.

Fig. 1.—A. Tuning-fork in the act of vibrating and giving off sound waves.
B. Sound waves generated by tuning-fork. These consist of condensations and rarefactions of the air, as indicated by the darker and lighter portions of the figure (after Dolbear).

Fig. 2.—Various forms of sound waves. *a, b, c,* Three simple sound waves. At *d,* the three simple waves are combined to form one compound wave. The organ pipe, designated the principal, gives out such a compound wave (after Dolbear).

Fig. 3.—Musical notation as determined by the number of vibrations per second. If the tuning-fork gives 256 vibrations per second, the note C on the added line (which is concert pitch) is produced: the note C an octave above it is produced by 512 vibrations per second. The intermediate notes (D, E, F, G, A) bear a mathematical relation to these two. Thus D is produced by $256 \times \frac{9}{8}$, or 288 vibrations, and so of the other notes in an ascending series (after Dolbear).

Fig. 4.—Battery or cell composed of platinum plate (*a*) and zinc plate (*b*) immersed in hydrochloric acid (*c*), in an open vessel. The plates are connected below by the acid, and above (in the air) by a wire (*d*): a current of electricity is generated, which travels in the direction of the dart (*e*).

Fig. 5.—Magneto-electric machine. *n. s,* Permanent horse-shoe magnet; *n′, s′,* short rods of soft iron fastened into a yoke-piece (*y*) also of soft iron. Coils of wire surround the rods (*n′, s′*), the ends of the wires connecting with each other and with a pole-changer. The horse-shoe magnet is fixed, but the other parts are free to rotate on the axis (*y, p*) by the pulley (*p*). When the machine is at rest the soft iron rods (*n′, s′*) are magnets by induction from their relation to the permanent magnet, but no electric current flows through the wires. Such a current is produced and flows through the wires when a rotatory motion is communicated to the pulley (*p*). In this case, the soft iron rods (*n′, s′*) are constantly made to change places in front of the north and south poles (*n, s*) of the fixed permanent magnet, and a current in one direction is generated (after Dolbear).

Fig. 6.—First form of speaking telephone. The sending or speaking-tube is expanded at one end. The expanded end is covered with taut gold-beater's skin, and has glued to its centre a piece of soft iron (*n, s*). *m,* Electro-magnet with its poles near, and opposite to, but not touching soft iron (*n, s*). One of the terminal wires of the electro-magnet (*m*) goes to the battery (*b*), and to a plate in the earth (*e*), the other to the receiving instrument (*r*). This consists of a tubular electro-magnet with coil enclosed in a tube of soft iron, the wire from which goes to a plate in the earth (*e′*). The receiver is provided with a loose thin disc of iron which acts as an armature to the electro-magnet (*r*). The current of electricity from the battery (*b*) makes *m* and *r* magnetic, and *m* makes the soft iron (*n, s*) inductively a magnet, with poles unlike the inducing electro-magnet. A current and circuit of electricity is thus furnished, and the parts are so arranged that the current can be influenced and made to pulsate by the vibrations of the voice entering in the direction of the dart and causing the soft iron (*n, s*) to move to and fro and alternately to touch and recede from the poles of the magnet *m.* The vibrations or pulsations produced by the voice are rapidly and accurately transmitted in waves to the receiver (*r*) and the armature, where they can readily be interpreted (after Dolbear).

Fig. 7.—Reiss's telephone. This instrument is simple and good for illustration, but imperfect. It consists of a hollow box with two apertures; one at the side with speaking-tube (*a*), the other at the top covered with stretched bladder, on the upper surface of which is glued a small aluminium plate (*b*). To this is connected a wire proceeding to the screw cup (*c*), from which a wire conducts to a battery. The other wire from the battery is fixed at the screw cup (*e*). Connecting the system of wires and stretched bladder armed with the platinum plate (*b*) is a platinum finger (*d*) fixed at *e,* but free to move at its other end. When the vibrations produced by the voice enter at *a,* the stretched bladder and platinum plate (*b*) vibrate in unison, and make and unmake the contact with the free end of the platinum finger (*d*), which, in turn, causes the current of electricity in the wires to pulsate sympathetically (after Reiss).

Fig. 8.—Professor Graham Bell's telephone. *p,* Speaking or sending end of instrument, consisting of mouthpiece with aperture, which admits the vibrations or sound waves produced by the voice to a thin iron disc (*d*), which vibrates sympathetically and transmits them to the magnet (*m*); this in turn induces a current in the coil of wire (*c*) and in the line waves (*w, w′*), through the terminals (*t, t*). When the instrument is used as a receiver, the pulsatory currents passed through the coil (*c*) cause the vibrating disc or diaphragm (*d*) to give out sounds which are heard by putting *p′* to the ear. The conditions are improved by employing a separate transmitter as invented by Mr. Blake and shown at Fig. 9 (after Graham Bell).

Fig. 9.—Mr. Blake's transmitter. "In this transmitter the vibrations or sounds are conveyed to the mouthpiece (*p*), which cause the vibrations of the air to impinge upon the diaphragm or vibrating disc (*d*), on the back and centre of which rests the point of a spring (*s*) carrying a small spherical-shaped piece of platinum which presses against a carbon block (*b*). The current passing through the primary of the induction coil (*i*) passes through the contact between the platinum and the carbon, and variations in the resistance of this contact due to the vibrations of the diaphragm cause currents to be induced in the secondary of the coil (*i*) which are sent into the line circuit" (after Blake).

Fig. 10.—Another speaking or sending arrangement. In this the mouthpiece (*a*) is large, the thin vibrating plate (*d, d*) being supported on the discs of a secondary carbon conductor (*c*) by a small iron cylinder (*b*). The pressure is regulated by a screw placed below *e.* The rigid disc (*f*) resting on the first platinum plate (*g*) is of aluminium (after T. A. Edison).

Fig. 11.—Early and unsuccessful form of telephone. *a, a′,* Funnel-shaped sending and receiving portions of instrument, the narrow ends of which are covered by taut gold-beater's skin; *b,* iron reed loosely attached by one extremity to uncovered pole of magnet, the other extremity being attached to the centre of the stretched gold-beater's skin at *c.* It was inferred that the membrane *c,* when thrown into vibrations by the voice, would transmit the vibrations unimpaired to the membrane *c′,* and that they would be given off at *a′.* The result was not satisfactory; the iron reeds (*b, b′*) being too heavy (after A. Graham Bell).

Fig. 12.—Arrangements for producing musical notes by electricity. When a bar of soft iron is surrounded by a coil of copper wire through which an electric current is passing it is converted into and remains a magnet as long as the current is flowing. It ceases to be a magnet the instant the current is cut off, and in ceasing to be a magnet it emits a click. If the clicks amount to 256 per second the note C is produced. The clicks are due to molecular changes occurring in the bar of soft iron when it is magnetised

PLATE CXLIII

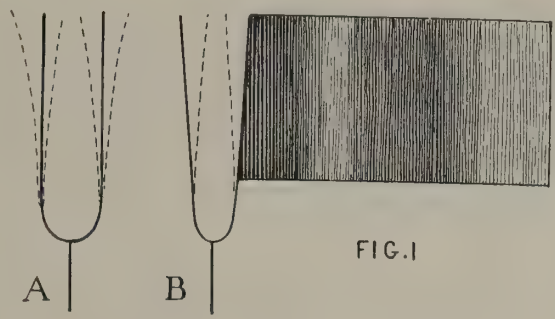

FIG. 1

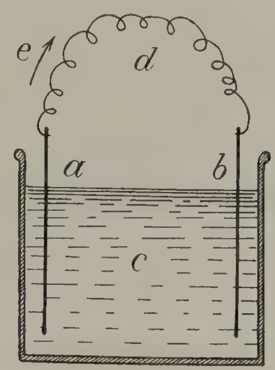

FIG. 4

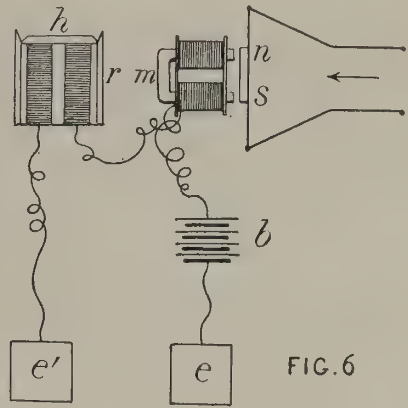

FIG. 6

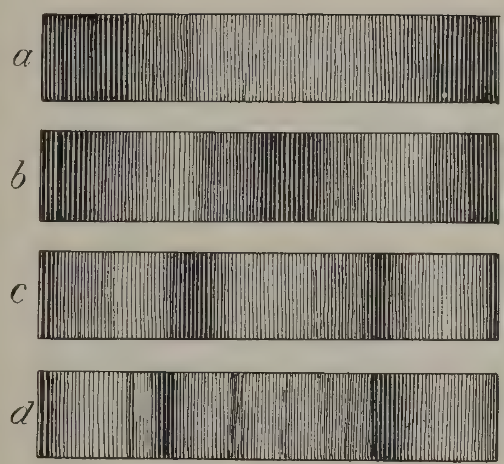

FIG. 2

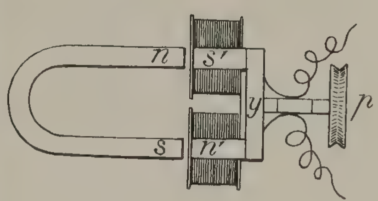

FIG. 5

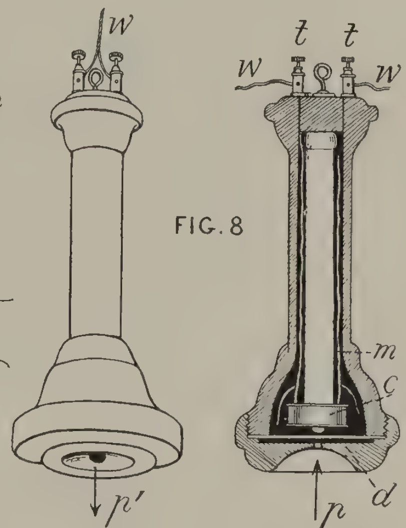

FIG. 8

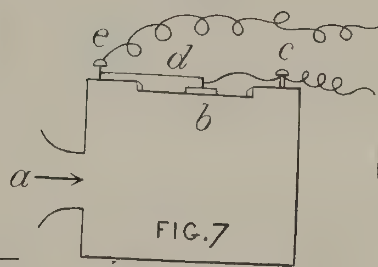

FIG. 7

C	D	E	F	G	A	B	C
1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2

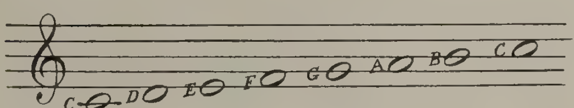

FIG. 3

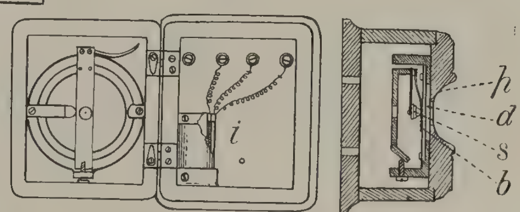

FIG. 9

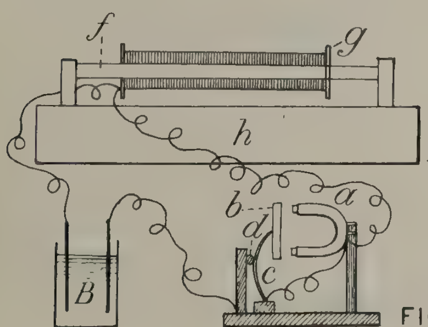

FIG. 12

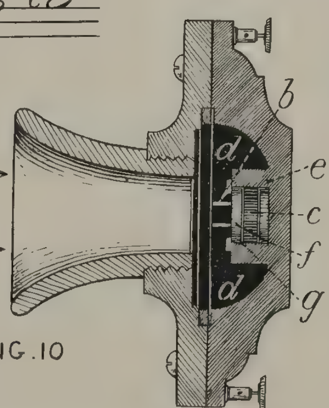

FIG. 10

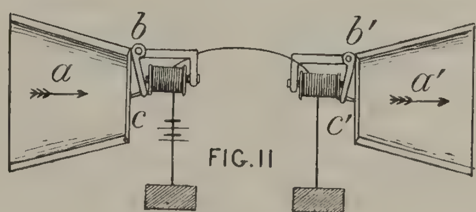

FIG. 11

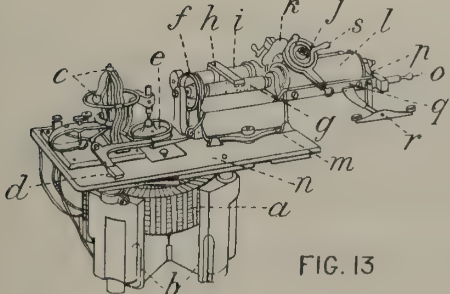

FIG. 13

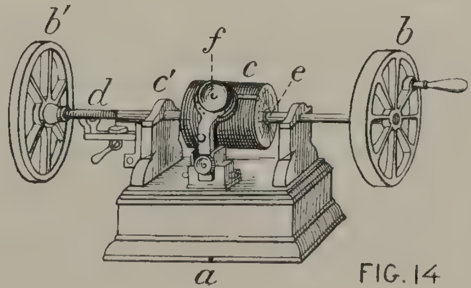

FIG. 14

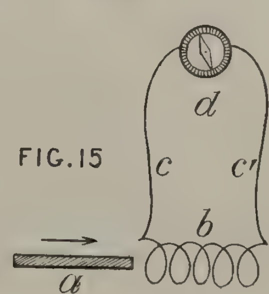

FIG. 15

PLATE CXLIII (*continued*)

and demagnetised. In the former case the bar is slightly elongated, and in the latter case shortened; the click is heard during its shortening process. It is the alternate starting and stopping or cutting off of the electric current which produces the clicks and notes. The clicks are intensified by placing the bar of soft iron with its insulated coil of copper wire on a wooden box or resonator. The pitch of the notes produced is determined by the force of the electric current, the slow or rapid breaking of the current, and the relative strengths of the magnet (*a*) and spring (*c*). *a*, Electro-magnet; *b*, armature of electro-magnet, fixed to a spring (*c*); *d*, metallic knob which completes the electric circuit when the spring (*c*) touches it. The circuit is made and broken by the opposing or counteraction of the electro-magnet (*a*) and the spring (*c*); the magnet attracts the armature (*b*) away from the knob (*d*); the spring forcing it towards the knob; *f*, bar of soft iron with coil of wire (*g*); *h*, wooden box or resonator on which *f* and *g* are placed.

B. Battery with wires going to the several parts of the apparatus (after C. G. Page).

Fig. 13.—Recent form of phonograph or speech-recorder. In the new form of phonograph, a cylinder of hard wax is substituted for that covered with tin-foil, and the instrument is driven by electricity. The parts are more numerous and complicated, but the additions constitute real improvements. *a*, Armature; *b*, field; *c*, governor; *d*, switch; *e*, main pulley on armature-shaft; *f*, pulley on cylinder-shaft; *g*, fixed screw; *h*, spring holding fixed-screw nuts; *i*, carriage; *j*, diaphragm; *k*, diaphragm-arm; *l*, cylinder on mandrel; *m*, body; *n*, bed-plate; *o*, lock-bolt; *p*, swinging arm; *q*, stop and start lift; *r*, keys to start lift; *s*, lever for changing diaphragm from recorder to reproducer (after T. A. Edison).

Fig. 14.—Early form of phonograph or speech-recorder, consisting of a box (*a*); two wheels (*b*, *b'*), one of them for driving; a cylinder with fine, spiral, continuous groove (*c*), mounted on a spiral axle of the same pitch (*d*), which can be made to rotate within spiral bearings (*e*, *c'*)—this insures that the cylinder and axle travel in the same direction and at the same speed; *f*, a mouthpiece, on the bottom of which is placed a thin, vibrating membrane or disc, armed at its centre with a needle-point or pricker. The cylinder (*c*) is covered with a sheet of tin-foil carefully adapted and fixed to its surface. The handle of the wheel (*b*) can be made to rotate from or towards the body of the operator, with the result that the cylinder (*c*) can be made to travel from right to left or from left to right. The travel of the cylinder is necessary to separate the pricks or indentations made by the point of the needle fixed in the membrane at the bottom of the mouthpiece when that membrane is made to vibrate by the voice in articulate speech. When the phonograph is spoken into, the voice is directed to the mouthpiece, and the cylinder (*c*) is made to revolve by the handle attached to the wheel (*b*). The voice, or strictly speaking, the vibrations produced by the vocal chords, are pricked into the tin-foil covering the spiral groove on the surface of the cylinder to various depths and at various distances. When the spoken words have been pricked into or indented on the tin-foil, the cylinder is brought back to its original position and made to rotate as at first. The needle-point of the vibrating membrane on the second excursion of the cylinder goes into every indentation originally produced so accurately that every peculiarity connected with the voice of the speaker is repeated and can be identified. When the voice *is taken in* by the phonograph the vibrations of the vocal chords producing the voice are separately and faithfully recorded by the vibrating membrane and its needle on the tin-foil. When the voice *is given off* by the phonograph the process is reversed: the needle-point, and the membrane in which it is fixed, are made to vibrate by the former going successively into all the indentations in the tin-foil, with the result that the original voice is reproduced with its subtle and marvellous details of intonation, inflexion, pitch, &c. What is true of articulate speech is also true of singing and instrumental music. The notes of a single instrument, or an orchestra, can be reproduced with equal facility (after T. A. Edison).

Fig. 15.—Illustrates magneto-electric action. The arrangement figured consists of a permanent bar magnet and a hollow helix of copper wire connected with a galvanometer. When the permanent magnet (*a*) is thrust into the hollow helix of wire (*b*) a current of electricity is generated (by induction) in the wire; the force of the current being increased according as the magnet passes through one or more coils of the helix—the more coils brought under the influence of the magnet the greater the strength of the current. The direction of the current is determined by the direction of the movement of the magnet, and is indicated by the needle of the galvanometer (*d*). If the magnet be withdrawn from the hollow helix, a current of electricity moves in an opposite direction through the whole circuit. As will be seen, the electric current produced in the wire is due to the presence of the magnet within the hollow coil: the current is *induced*. When the magnet is withdrawn the current disappears in an inverse order. The amount of electricity that can be produced by *induction* is practically unlimited and depends on the strength of the magnet, the thickness of the wire, and the length of wire in the coil. The converse of this holds true. If a current of electricity be made to pass through a coil of copper wire, and a bar of soft iron be placed within the coil, the bar of soft iron is converted into and remains a magnet so long as it is under the influence of the coil. The law of "induction" was first demonstrated by Professor M. Faraday (after Dolbear).

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of sound waves or movements) from the atmosphere, or it will generate and transmit counter-movements to the atmosphere. It is at once the receiver and the reproducer of sound. In other words, it receives the delicate and multitudinous impacts or touches produced by the contact of myriads of air particles thrown into wave motion by some vibrating body in its vicinity; or, conversely, it throws the tangible and innumerable air particles in contact with itself, into waves when its disc is made to vibrate. In its former capacity it resembles the human ear, which, as we shall see presently, receives and transmits sonorous waves to the human brain. In its latter capacity it resembles the human vocal chords, which, when they are made to vibrate in the effort of speaking, throw the air particles into waves—the sonorous or sound waves of physicists.

The manner in which sound is produced may be readily illustrated, by a very simple experiment.

If the end of a drum be struck with a drum-stick, the sheepskin forming the end of the drum is thrown into vibration, and the sound produced is greatly intensified by the cavity of the drum, which acts as a resonator. The particles of air agitated by the vibrating end of the drum execute a to and fro motion, and alternately approach towards and recede from each other, so as to occasion alternate condensations and expansions of the atmosphere. In this way sonorous, or sound waves, are produced, and the sonorous waves always maintain the same length originally imparted to them by the vibrating or sounding body.

The sound vibrations in air follow each other like circles of waves on the surface of water when a stone is thrown into it.

The sheepskin forming the end of the drum can be seen to vibrate. It is a material, tangible substance, and the atmosphere in contact with its free surfaces is likewise a material and tangible substance when agitated. The sheepskin cannot be made to vibrate without causing the air particles with which it is in contact also to vibrate, and the near air particles in turn influence the more and more remote air particles, until the primary motion exhausts or dissipates itself. In reality, the vibrating end of the drum throws the air particles into waves, and these travel further and further afield at a certain speed, and as they do so, they produce a sound which decreases in intensity according to the distance it travels, or in proportion as it recedes from the original source of sound. Sounds therefore travel at given speeds and for certain distances. Sounds consequently cannot be heard beyond certain distances, and they are heard at once, or on the instant, only when the listener is in the immediate vicinity of the vibrating body producing the sound. If, for example, one be far removed from a big gun when it is being discharged, the flash is seen from the muzzle of the piece long before the report is heard. The same holds true of the hammer of the quarryman and the axe of the woodman, at work in the distance. The stroke is perceived by the eye of the spectator long before the report caused by the stroke reaches the ear.

The sounds produced by the end of the drum, the firing of the big gun, and the stroke of the hammer and axe vary less in kind than in degree. They are all the result of material substances thrown into vibration, which react upon the air.

Numerous other illustrations may be given. If a tuning-fork be struck, the strings of a harp or violin be twitched, or the strings of a piano or dulcimer hammered, the legs of the tuning-fork, the strings, and the air in contact with them are thrown into vibration, and produce sounds, notes, or tones varying in intensity, quality, and pitch (Fig. 1, Plate cxliii.).

Sounds are divisible into noises and musical notes or tones. A musical tone is produced when any elastic body is made to perform regular periodical vibrations at a certain speed. It can, however, also be produced directly by a vibration of the air, as when we blow across the mouth of a bottle or Pan's pipe.

A tone is distinguished by (*a*) its strength or intensity, (*b*) its quality (timbre), and (*c*) its pitch. The intensity of the tone depends on the *extent or amplitude* of the sound waves, the quality or timbre on the *form* of the sound waves, and the pitch on the *length* of the sound waves; the longer the waves, the deeper the tone—the shorter the waves, the higher the tone. The pitch of the tone consequently increases with the number of vibrations performed in a given time.

If the vibrations produced in the sounding body are fewer than sixteen in the second, they are heard as a series of distinct or separate taps.[1]

If the vibrations just exceed sixteen to the second, the taps run more or less into each other, and produce a very low, coarse, continuous sound or note, similar to that produced by the landrail or corncrake, or by running a piece of wood rapidly over the teeth of a saw.

In proportion as the vibrations increase in number the tones or notes become higher and sharper. Thus the note C (contra octave) is produced by thirty-three vibrations in the second; the note C (great octave) by sixty-six vibrations; the note C (small octave) by 132 vibrations, and so on.

The piano, our standard instrument for harmony, begins with the C of thirty-three vibrations; occasionally, however, with the A of 27·5 vibrations, the highest note being the a'''' of 3520 vibrations.

Musical tones or notes are, for physical and physiological reasons, divided into octaves of eight notes each; and the octaves are seven in number; so that there are fifty available musical notes. The notes not embraced in the seven octaves are either too low or too high to be agreeable. Curiously enough, the organ of the human ear, as designed for musical perception, is only adapted for seven octaves; this being also the arrangement met with in the organs of Corti in the cochlea of the inner ear, already described.

This digression on the production of sound and musical notes naturally leads to a consideration of the human voice.

§ 243. Mechanism of the Human Voice.

The human voice is produced by the vibration of the vocal chords, &c., situated within the larynx, the larynx itself being an expanded portion of the trachea or windpipe, which communicates with the mouth, nose, and lungs (Plate cxliv. p. 866). The larynx and the cavities to which it leads act as resonators to the vocal chords. As the lungs, mouth, nose, and trachea are always more or less completely filled with air during the movements of respiration in the living subject, it follows that the surfaces of the vocal chords are in contact with air particles in every

[1] Helmholtz found, by experimenting with closed organ-pipes and large tuning-forks, that a note only became musical when produced by twenty-eight or thirty vibrations per second; deeper tones creating a buzzing or groaning sound. It is the nervous apparatus of the ear which combines or runs together the vibrations entering into the composition of musical notes.

PLATE CXLIV

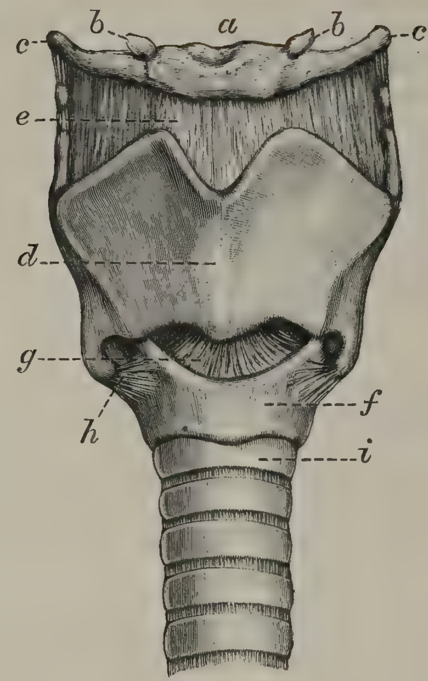

Fig. 1.

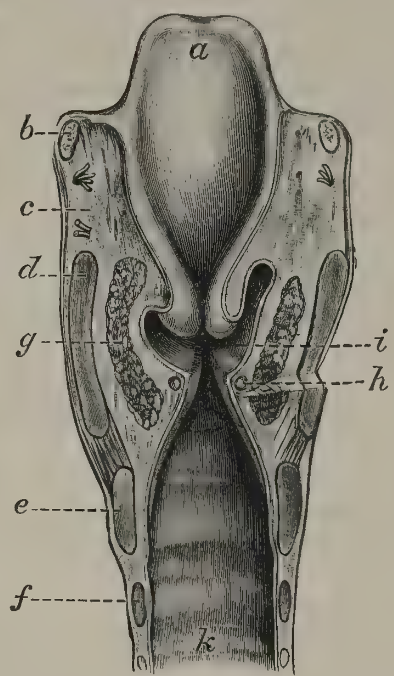

Fig. 2.

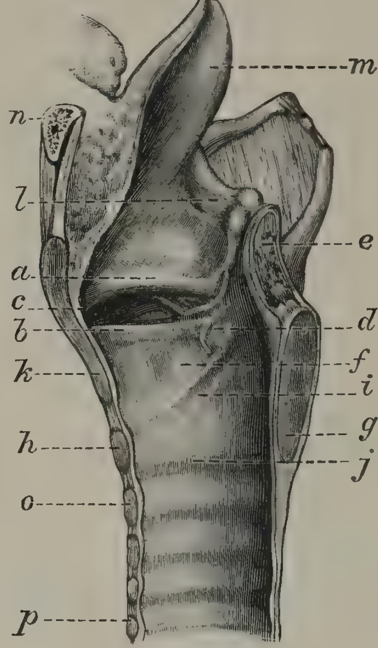

Fig. 3.

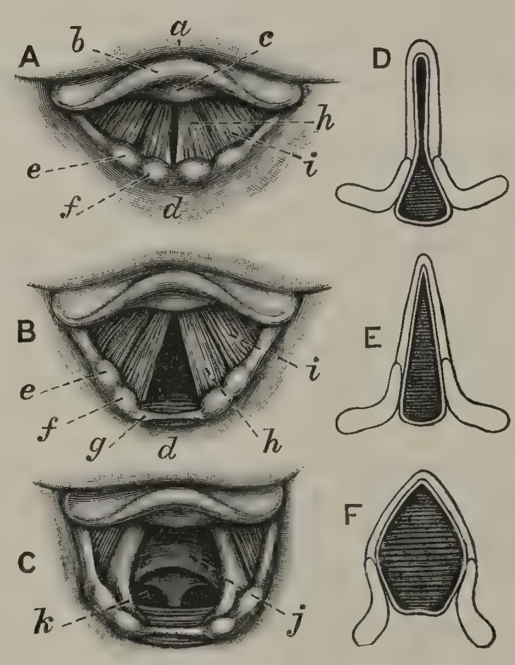

Fig. 4.

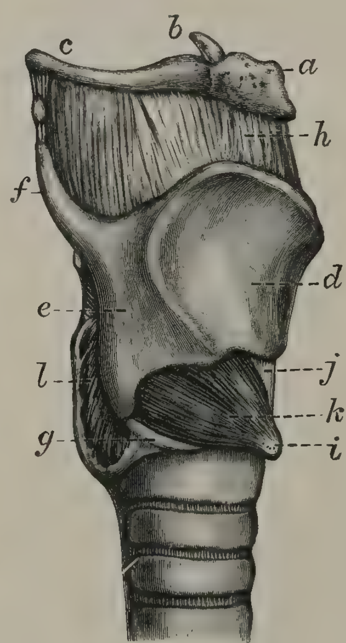

Fig. 5.

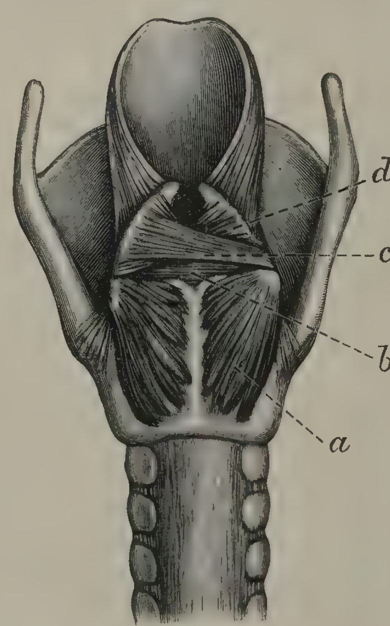

Fig. 6. BUTTERWORTH Sc

direction. As, moreover, the larynx, within which the vocal chords are situated, is provided with numerous delicate muscles, the movements of which are definitely co-ordinated, it follows that by an effort of will the muscles in question can be made to contract and relax, so as to cause the vocal chords to separate or come together, to lengthen or shorten, and to vibrate at varying degrees of speed, when in the act of speaking.

When the chords are long and the vibrations are few in number, the note produced is low; when the chords are short and the vibrations numerous, the note is high.

In this respect the human voice is the product of a stringed instrument (the vocal chords, &c., placed within the larynx); and the pitch of the voice is determined by the number of vibrations, precisely as in other stringed

PLATE CXLIV

Plate cxliv. shows the organ of voice, composed of bones, cartilages, ligaments, membranes, muscles, &c.

FIG. 1.—Cartilaginous box of larynx with laryngeal cartilages and ligaments—front view. *a*, Hyoid bone; *b*, *b*, its small cornua; *c*, *c*, its large cornua; *d*, thyroid cartilage; *e*, thyro-hyoid membrane; *f*, cricoid cartilage; *g*, crico-thyroid membrane; *h*, lateral crico-thyroid ligament; *i*, uppermost ring of trachea (after Sappey).

FIG. 2.—Anterior half of section of larynx near its middle. Shows narrow aperture or chink (rima glottidis) through which the air passes in breathing and in the formation of voice. *a*, Free part of epiglottis; *b*, great cornu of hyoid bone; *c*, thyro-hyoid membrane; *d*, thyroid cartilage; *e*, cricoid cartilage; *f*, first ring of trachea; *g*, thyro-arytenoid muscle; *h*, inferior thyro-arytenoid ligament in membrane of true vocal chord at the rima glottidis; *i*, the ventricle with the false vocal chord above it; the narrow passage or chink (rima glottidis) through which the air passes during respiration and the formation of voice is clearly shown; *k*, interior of trachea conducting to the lungs (after Thomson).

FIG. 3.—Interior of right half of larynx, showing superior (false) and inferior (true) vocal chords *in situ*. *a*, Superior or false vocal chord; *b*, inferior or true vocal chord; *c*, ventricle; *d*, arytenoid cartilage covered with mucous membrane; *e*, arytenoid muscle cut across; *f*, slope of crico-thyroid membrane conducting to inferior or true vocal chord; *g*, *h*, sections of cricoid; *i*, *j*, its upper and lower borders; *k*, section of thyroid; *l*, upper part of larynx; *m*, section of epiglottis; *n*, section of hyoid bone; *o*, *p*, trachea (after Sappey).

FIG. 4.—Three laryngoscopic views from life of upper aperture of larynx, showing vocal chords, glottis, and surrounding parts in different states.

A. Shows the glottis and vocal chords during the emission of a high note in singing; B, in natural inhalation of air; C, in inhaling a very deep breath. Diagrams D, E, F show horizontal sections of glottis, positions of vocal ligaments, and arytenoid cartilages in states corresponding to A, B, C. The same letters apply to the same parts as in A, B, C (after Sappey).

A, B. *a*, Base of tongue; *b*, upper free part of epiglottis; *c*, tubercle or cushion of epiglottis; *d*, portion of anterior wall of pharynx behind larynx; *e*, swelling caused by cuneiform cartilage; *f*, swelling caused by corniculum; *g*, tip of arytenoid cartilages; *h*, inferior or true vocal chords forming lips of rima glottidis or breathing aperture; *i*, superior or false vocal chords with ventricle of larynx between.

C. *j*, Anterior wall of receding trachea; *k*, beginning of the two bronchi beyond the bifurcation (after Czermak).

FIG. 5.—Muscles of the larynx as seen from right side. *a*, Hyoid bone; *b*, *c*, its cornua; *d*, right ala of thyroid cartilage; *e*, posterior part of thyroid cartilage; *f*, upper cornu of thyroid; *g*, lower cornu of thyroid; *h*, thyro-hyoid ligament; *i*, anterior part of cricoid; *j*, crico-thyroid membrane; *k*, crico-thyroid muscle; *l*, posterior crico-arytenoid muscle.

FIG. 6.—Muscles of the larynx as seen from behind. *a*, Posterior crico-arytenoid muscle; *b*, arytenoid muscle; *c*, *d*, oblique muscular fibres passing round edge of arytenoid cartilage to join thyro-arytenoid muscle and form arytenoid-epiglottic muscle (*e*) (after Sappey).

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instruments. The anatomy of the larynx, vocal chords, and muscles is given on Plate cxliv., and will greatly assist the reader in mastering the details of a very intricate but interesting subject.

The larynx, vocal chords, and muscles require a passing word. The larynx is a curious, irregularly shaped, cartilaginous box, composed of nine pieces. It is an important structure for two reasons. First, it is largely concerned in respiration; and second, it plays a principal part in the formation of voice. Two sets of muscles are required for its physiological action, namely, the respiratory muscles, by the aid of which we breathe, and the laryngeal muscles, by the aid of which we produce vocal sounds.

The larynx and vocal chords are mainly concerned in the production of voice. "The accessory organs are the lungs, trachea, and expiratory muscles, and the mouth and resonant cavities about the face. The lungs furnish the air by which the vocal chords are thrown into vibration, and the mechanism of this action is merely a modification of the process of expiration. By the action of the expiratory muscles the intensity of vocal sounds is regulated."

The larynx has its own peculiar or intrinsic muscles, eight in number: five of these being connected with the vocal chords and rima glottidis (the chink through which we breathe) and three with the epiglottis, an accessory structure.

The muscles of the vocal chords and glottis are the crico-thyroid, the posterior crico-arytenoid, the lateral crico-arytenoid, the arytenoid, and the thyro-arytenoid: the muscles of the epiglottis being the thyro-epiglottid, and the aryteno-epiglottid superior and inferior.

The muscles of the larynx are conveniently divided into (*a*) those which open and close the glottis; and (*b*) those which regulate the degree of tension in the vocal chords.

The glottis is opened, and the vocal chords separated, by the posterior crico-arytenoids. It is closed by the arytenoid, the lateral crico-arytenoids, and the thyro-arytenoids.

The vocal chords are tightened and elongated by the crico-thyroids, and relaxed and shortened by the thyro-arytenoids.

The epiglottis is depressed by the thyro-epiglottid; the aryteno-epiglottids, superior and inferior, constricting the apertures of the larynx and compressing the laryngeal sac.

The vocal chords, on the integrity of which the production of voice mainly depends, are four in number; two superior or false chords, and two inferior or true chords. The latter only fall to be considered. The inferior or true vocal chords are two fibro-elastic structures stretched across the upper opening of the larynx, and in such a

position that they are more or less parallel. They are free to vibrate; their inner margins forming the important chink or aperture, known as the rima glottidis.

By forcing the air from the lungs upon the vocal chords, as in the production of voice, they are thrown into vibrations which are more or less frequent and pronounced according to the effort put forth. The air from the lungs causes the vocal chords to vibrate in the first instance; but the vocal chords cause the air to vibrate in the second instance. The vocal chords at once receive vibratile impulses from the air, and communicate vibratile impulses to it; and it is the latter, namely, the vibrations given off by the vocal chords to the air, which produce the voice.

"If the glottis be exposed in the living animal by opening the pharynx and œsophagus on one side, and turning the larynx forwards, it will be seen that so long as the vocal chords preserve their usual relaxed position during

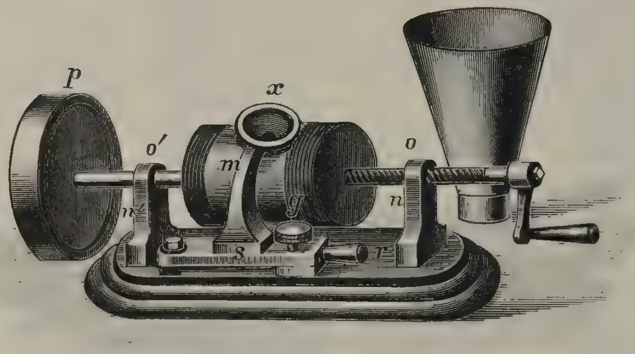


Fig. 231.

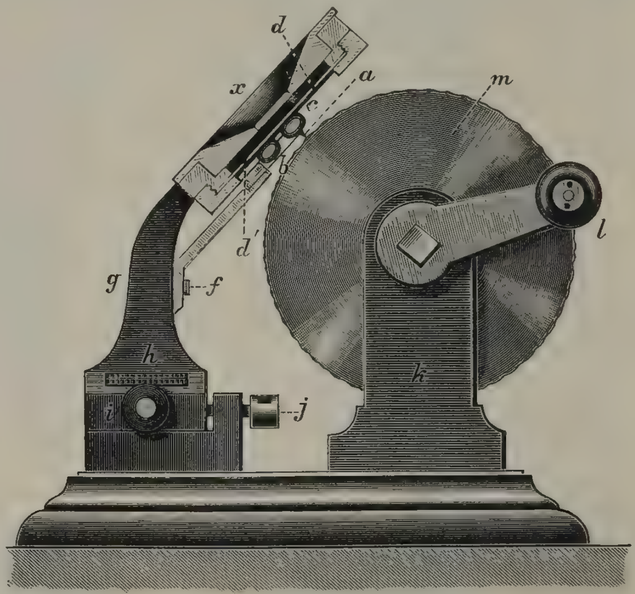


Fig. 232.

Figs. 231 and 232 —The instrument in these figures consists of a registering cylinder (*m*), set in motion by the hand of a winch (*l*), before which a vibrating plate is placed, furnished on its face with a telephone mouthpiece (*x*), and on the reverse side with a tracing point. This tracing point, which is seen at *s* (*g* in the section of the instrument given at Fig. 232), is not fixed directly to the plate; it rests on a spring (*b*), and a caoutchouc pad (*c*) is placed between it and the vibrating disc. The cylinder, of which the axis (*n*, *n*, Fig. 231) is cut at one end like a screw, to enable it to make a lateral progressive movement simultaneously with the rotatory movement effected on itself, has on its surface a narrow screw-thread coinciding with that of the axis, and when the tracing point is inserted, it is able to pass along it for a distance corresponding to the time occupied in turning the cylinder. A sheet of tin-foil or of very thin copper is carefully applied to the surface of the cylinder, and it should be slightly pressed down upon it, so as to show a faint tracing of the groove, and to allow the point of the vibrating disc to be placed in a proper position. The point rests on the foil under a pressure which must be regulated, and for this purpose, as well as to detach the cylinder when it is desired to place or take away the tin-foil, there is the articulated system (*s*, *r*) which sustains the support of the vibrating disc. This system consists of a jointed lever in which there is a nut-screw for the screw (*g*). The handle (*r*) at the end of the lever allows the tracing system to be turned aside when the screw (*g*) is loosened. In order to regulate the pressure of the turning point on the sheet of tin-foil, it is enough to turn the screw (*g*) loosely in its socket, and to tighten it as soon as the right degree of pressure is obtained (after Du Moncel).

respiration, no sound is heard, except the ordinary faint whisper of the air passing gently through the cavity of the larynx. When a vocal sound, however, is to be produced, the chords are suddenly made tense and applied closely to each other, so as to diminish very considerably the size of the orifice; and the air, drawn by an unusually forcible expiration through the narrow opening of the glottis, in passing between the vibrating vocal chords, is itself thrown into vibrations which produce the sound required. The tone, pitch, and intensity of this sound vary with the conformation of the larynx, the degree of tension and approximation of the vocal chords, and the force of the expiratory effort. The narrower the opening of the glottis, and the greater the tension of the chords, under ordinary circumstances the more acute the sound; while a wide opening and a less degree of tension produce a graver note. The quality of the sound is also modified by the length of the column of air included between the glottis and the mouth, the tense or relaxed condition of the walls of the pharynx and fauces, and the state of dryness or moisture of the mucous membrane lining the aërial passages.

"Articulation on the other hand, or the division of the vocal sound into vowels and consonants, is accomplished entirely by the lips, tongue, teeth, and fauces." [1]

The production of vocal sounds, it will be seen, depends largely upon the tension and position of the vocal chords as regulated by the muscles of the larynx already referred to.

[1] "Human Physiology," by Professor John C. Dalton, 5th edition, p. 478.

The process by which voice is produced in the living subject may be readily imitated in the dead subject.

If the trachea and the larynx with its vocal chords be removed in a fresh condition, and a bellows attached to the lower or cut end of the trachea, all that is necessary to produce voice is to vary the tension, length, and position of the vocal chords, and to regulate the currents of air proceeding in a direction from below upwards. In this case the air currents furnished by the bellows are to the vocal chords what the indented tin-foil and needle are to the vibrating disc of the phonograph.

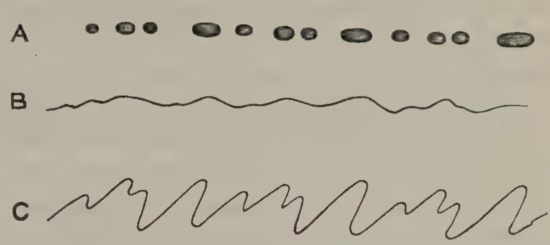


Fig. 233.—A corresponds to the letter *a* when pronounced as in "bat." It is an enlarged reproduction of the tracing left on the tin-foil. B represents its profile on the sheet of smoked glass; and C shows the outline of Koenig's singing flames, when the same sound is produced quite close to the membrane of the register (after Du Moncel).

The voice may further be imitated by purely artificial means. This is done by the aid of an artificial trachea and larynx over which are stretched two sheets of india-rubber, whose free edges are nearly parallel, and which represent the vocal chords. By blowing into the tube representing the windpipe of the artificial larynx, the two sheets of india-rubber are separated, and the slit between them widened. Their elasticity brings them together again, and so a periodical interruption of the current of air may be produced —sounds greatly resembling the human voice being generated.

That the production of the human voice is primarily due to the vibration of the vocal chords, is a matter of observation and experiment.

By the aid of the laryngoscope, an instrument consisting of an arrangement of mirrors for looking into the larynx, the vocal chords can be distinctly seen to vibrate when a note is sounded; the pitch of the note being low or high, according to the number of vibrations.

Here we have a proof of the manner in which voice is produced in the healthy subject. In the diseased subject, the proof, although of a negative kind, is still more striking.

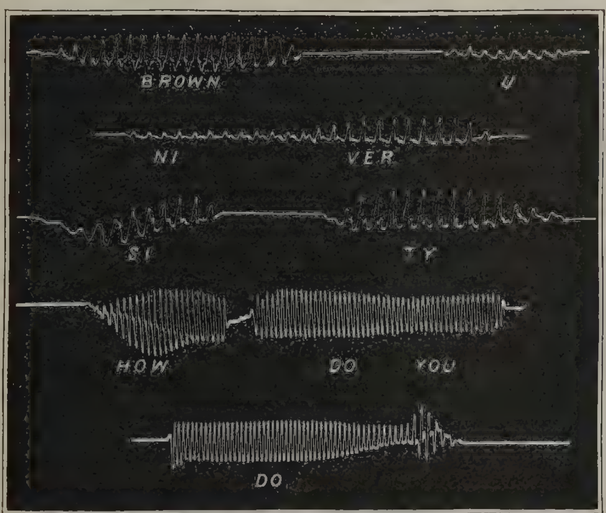


Fig. 234.—Represents an extremely curious tracing of the vibrations produced by the words "Brown, university: how do you do?"[2]

Thus, if one or both of the vocal chords be thickened by inflammation, or swelled by cold or unhealthy infiltration, so that the vibrations of the chord or chords are interfered with, the voice is rendered husky or altogether destroyed.

That the laryngeal muscles also play an important part in the production of voice, is equally clear from the fact that division or destruction of the inferior laryngeal nerves (the nerves which excite and co-ordinate the movements of the laryngeal muscles) is followed by the loss of voice.[1]

So much for the production of the human voice in its relation to the phonograph. It is now necessary to direct attention to the phonograph in its relation to the human ear.

The phonograph, as has been already explained, consists of (*a*) a funnel-shaped portion, its sound receiver and distributor comparable to the mouth and external ear; (*b*) a vibrating disc, comparable to the *membrana tympani*, or drum of the ear; (*c*) a needle attached to its vibrating disc, comparable to the chain of ossicles or small bones of the middle ear, which transmits its vibrations to the tin-foil on the cylinder; (*d*) the tin-foil on the cylinder, which receives the impacts or indentations of the needle, comparable to the *membrana fenestræ ovalis*, a sort of inner drum of the ear; and (*e*) the screw surfaces of the cylinder and its axle, which separates the impacts or indentations made by the needle in the tin-foil, which bear the same relation to the needle and the needle indentations which the rods of Corti bear to the several sound waves entering the ear. The screw surfaces divide and analyse the vibrations or sounds transmitted to the phonograph from without.

A careful representation of a phonograph is given at Fig. 231. A side view of the same instrument is given at Fig. 232. The vibrations produced by the human voice are depicted at Figs. 233 and 234.

[1] Much interesting information regarding the physiology and pathology of the larynx will be found in "The Physiology of the Larynx," *Edinburgh Medical Journal*, 1866, and "The Disorders of Speech," 1874, by Dr. John Wyllie, LL.D., Professor of Medicine in the University of Edinburgh.

[2] "The Telephone, &c.," by Count du Moncel, p. 331.

§ 244. Mechanism of the Human Ear.

The anatomy of the human ear is very complex in one sense, but very simple in another.

It is complex as to the number of its parts, and simple as to its principle of construction.

The ear is to be regarded as the receiver and transmitter of sound to the brain. It informs the brain when vibrating bodies are in its vicinity, and this is done by the aid of all the substances which intervene between the sounding body and its own substance.

The substances engaged in the production of sound and hearing are very various.

1st. There is the vibrating or sounding body itself.

2nd. The substance of the atmosphere ; and

3rd. The several substances entering into the composition of the ear. The following may be mentioned : membranes, fibres, muscles, nerves, cartilages, bones, earthy concretions, bristles, hairs, waxy secretions, aëriform and watery fluids, and the so-called organs of Corti.

The rods of Corti are vibrating structures, and their function is to strike and incite the delicate terminal filaments of the auditory nerves. They are some 3000 in number, and as they vibrate in harmony with only certain notes, it follows that all the notes capable of being appreciated by the human ear are amply represented.

Of the 3000 rods of Corti, 2800, according to Helmholtz, may be distributed among the seven octaves containing the musical notes in general use. This gives 400 to every octave, and $33\frac{1}{3}$ to every semitone.

The earthy concretions or otoliths, and the hair and rod-like processes found in the inner chamber of the human ear, are highly interesting structures, from the fact that they communicate directly or indirectly with the auditory nerves leading to the brain.

The terminal filaments of the auditory nerves are distributed on the membranes found in the *vestibule*, the *ampullæ*, the semicircular canals, and the *lamina spiralis* of the cochlea. On the membranes of the *ampullæ*, and obviously connected with the delicate terminal filaments of the auditory nerves, are certain long, stiff, hair-like processes, which, being thrown into vibration by the fluids of the internal ear in the transmission of sound, directly influence or incite the nerves of hearing.

Similar remarks are to be made of the earthy concretions, otoliths, or ear stones. Still more remarkable in some respects is the arrangement of the rods of Corti and nerve endings in the *lamina spiralis* or partition of the cochlea, which winds from the base to the summit of the cochlea in a spiral manner, and makes rather over two turns in doing so. The *lamina spiralis* is partly bony and partly membranous, and it is the membranous portion which is so remarkable.

This portion consists of certain transverse fibres arranged in parallel rows like harp or dulcimer strings, which there is reason to believe are capable of being thrown, in whole or in part, into sympathetic vibration by sounds entering the inner chamber of the ear. On these transverse fibres are reared certain other fibres in the form of an arch or bow. These are the famous rods of Corti already alluded to (Figs. 2, 3, 4, 5, and 6 of Plate cxxxix., p. 762, and Fig. 5 of Plate cxl., p. 763).

The rods of Corti are composed of two sets of *s*-shaped fibres placed on end, which increase in length and diminish in height from the base to the summit of the cochlea. As they are capable of being thrown into vibration by the fluids of the internal ear, they are the instruments designed by nature for enabling us to hear tones of various pitch.

The rods of Corti, with their resonating, transverse fibres, greatly resemble in structure and function the several parts of a piano, to which they may not inaptly be compared. They are freely vibrating structures, and a certain number of them, or parts thereof, vibrate in unison with every note that can be heard.

As each Cortian rod and transverse fibre communicates directly or indirectly with a terminal filament of the auditory nerve, it follows that no sound transmitted to the cochlea in the inner ear can remain unappreciated by the brain.

Bernstein remarks :—

"In the cochlea we have to do with a series of apparatus adapted for performing sympathetic vibrations with wonderful exactness. We have here before us a musical instrument which is designed, not to create musical sounds, but to render them perceptible, and which is similar in construction to artificial musical instruments, but which far surpasses them in the delicacy as well as the simplicity of its execution. For, while in a piano every string must have a separate hammer by means of which it is sounded, the ear possesses a single hammer of an ingenious form in its ear bones, which can make every string of the organ of Corti sound separately. . . . The sympathetic vibratory apparatus in the labyrinth, and particularly in the cochlea, further possesses the important property that it does not continue the vibrations after the sounds have ceased."

From the account given of the human ear it will be seen that its outer and middle chambers, in addition to other things, contain air, and that its inner chamber, in addition to the various substances enumerated, contains fluid. There is thus continuity of substance from without inwards.

The *membrana tympani*, or outer drum of the ear, vibrates in air—it having air on either side of it. The *membrana fenestræ ovalis*, or inner drum of the ear, vibrates partly in air and partly in fluid, it having air on its outer and fluid on its inner surface.

The several parts of the ear are admirably adapted for receiving and transmitting sound.

When the air waves produced by the vibration of some sounding body reach the external ear, they are collected by its funnel-shaped cavity, and in a concentrated form strike or smite the *membrana tympani*, or outer drum of the ear. This is thrown into vibration. When the outer drum vibrates it causes the chain of small bones occupying the middle ear to vibrate ; these, in turn, causing the *membrana fenestræ ovalis* or inner drum to vibrate. When, however, the inner drum vibrates, it causes the fluids contained in the inner ear to vibrate or surge in waves, which waves impinge against, and strike in the most delicate manner possible, the otoliths and hair and rod-like processes (the rods of Corti), which in turn strike the ultimate filaments of the auditory nerves ; these, as is well known, communicating with the brain, which is the last substance to be struck.

The sense of hearing, it will be perceived, requires for its operation—

1st. A vibratile or sounding body situated somewhere in the external world.

2nd. An atmosphere of matter, extending between the sounding body and the ear.

3rd. The organ of hearing, composed of the several parts and structures already adverted to.

Sounds may approach the human ear either directly or indirectly. Thus they may approach it indirectly by means of the air, as explained ; or they may approach it directly, in the absence of air, by the bones of the head. If, for example, we strike a tuning-fork and place it in the mouth, we hear no sound ; if, however, we apply it to the teeth, its tone becomes at once audible. In this case the vibrations of the tuning-fork are conveyed to the labyrinth of the ear through the skull, and do not pass either through the tympanic cavities or ear bones.

In dealing with the structures of the organ of hearing, we are dealing with things quite as tangible in their way as the parts of the phonograph ; and, indeed, and as has been already stated, the organ of hearing and the phonograph bear a remarkable resemblance to each other. Similar remarks are to be made of the phonograph and the organ of voice (vocal chords). In reality the phonograph, the organ of voice, and the organ of hearing are constructed on essentially the same principles ; an intelligent appreciation of the former involving of necessity an intimate acquaintance with the two latter. In the phonograph the organs of voice and hearing are both represented, art and science, as it were, leaning upon nature. If proof were wanting of the important bearing of science upon nature, it would be found in the extraordinarily complicated, and yet, in some senses, simple relations which obtain between the phonograph on the one hand, and the organs of voice and hearing on the other. Such proof, however, is unnecessary, as science is simply nature in a human garb. Man does not create. He only discovers and applies. In other words, he cannot invent what does not exist in nature in some shape or other ; he cannot find out laws and principles which would apply to non-existent matter. Edison, in discovering the phonograph, only availed himself of already existing materials, but in appropriating and utilising these materials he displayed so much ingenuity, and such a profound knowledge of natural law, that he is fairly entitled to be regarded as one of the greatest inventors of modern times.

§ 245. Structure and Working of the Telephone.

Having described the phonograph more or less in detail, and the anatomy and physiology of the human voice and ear, I am now in a position to describe the telephone, which acts on a common principle with the phonograph, voice, and ear, but which invokes the aid of electricity in its operations (Fig. 235).

The first form of telephone was a very simple affair, and consisted of two cylinders, one end of each being covered with a piece of stretched parchment, in the centre of which was fixed, by the aid of a flat button, a cord (silk by preference) which might measure from 20 to 100, or 1000 or more feet.

The operators had simply to take their places and stretch the cord tightly. The instrument having the same structure at both ends of the cord, the operator at either end could either speak or listen. The parchment-covered cylinder at each end of the cord could either receive or deliver a message. The cylinders with their continuous cord transmitted ordinary speech and even whispers.

The *modus operandi* was briefly as under. The operator sending the message spoke into the *open* end of the cylinder and caused the stretched membrane there to vibrate ; the vibrations travelled along the taut string and produced sympathetic and identical vibrations in the stretched parchment of the other cylinder, the open end of

which was placed to the ear of the individual receiving the message. The original telephones could not be worked satisfactorily for more than 2000 or 3000 feet, and an attempt was soon made to introduce insulated wires and electricity as conducting media.

This was a difficult but not an insurmountable task. I have stated that when a current of electricity is passed through a coil of copper wire which surrounds a rod of soft iron, the latter is converted into *a temporary magnet*—also that the iron loses its magnetic properties the instant the current ceases. This gives an interrupted current.

"It was observed that a magnetic bar could emit sounds when rapidly *magnetised and de-magnetised*, and these sounds corresponded with the number of currents which produced them."[1]

"If the rod of soft iron be of considerable size, say a foot or more in length, and half an inch or more in diameter, and the current be strong enough to make a powerful magnet of it, whenever the current from the battery is broken, the bar may be heard to give out a single *click*.

"This will happen as often as the current is broken, and is occasioned by a molecular movement which results *in a change in the length* of the bar.

"When it is made a magnet *it elongates* about $\frac{1}{25000}$ths of its length, and when it loses its magnetism it suddenly regains its original length and develops the click.

"The sound was first heard by Professor Page of Salem, Mass., in 1837.

"If some means be devised for breaking such a circuit more than fifteen or sixteen times per second we shall have a continuous sound with a pitch depending on the number of clicks per second; 256 clicks per second producing the pitch C.

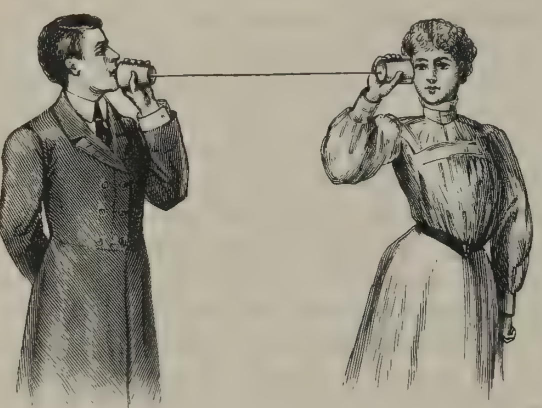


FIG. 235.—Early form of telephone. A more elaborate form of telephone is seen at Fig. 236.

"Professor Page was the first to invent the necessary apparatus (Fig. 12, Plate cxliii., p. 863). He fixed the armature of an electro-magnet to a spring which was in circuit when the spring was pressing against a metallic knob, at which time the current made the circuit in the coil of the electro-magnet. The magnet, attracting the armature away from the knob or button, *broke the circuit*, which, of course, destroyed the magnetism of the magnet and allowed the spring to fly back against the button and complete the circuit and reproduce the same series of changes.

"The rapidity with which the current may be broken in this way is only limited by the strength of both the spring and the current. The greater the tension of the spring with a given current the greater number of vibrations will it make.

"Suppose such an *intermittent* current to pass through the coil surrounding a soft iron rod 256 times per second, then the rod would evidently give 256 clicks per second, which would have the pitch of C.

"When these clicks are produced in the rod as held in the hand they are feeble, as in the tuning-fork when so held.

"It is necessary, therefore, to place the rod on a resonant surface, and this can be done by mounting it on a box with one or two holes in its upper surface, after the manner of an Æolian harp.

"The wire through which the sound is transmitted may evidently be of any length, the magnetised rod and box responding to the number of vibrations of the spring how long soever the circuit may be."[2]

§ 246. The Reiss (musical) Telephone.

The ease with which membranes are thrown into vibrations corresponding in period to that of the sounding body has been already explained in the case of the ear, and attempts have been made from time to time to make vibrating membranes available for telephony.

Herr Reiss made such an attempt in 1861. In this year (*vide* Fig. 7, Plate cxliii.) he made a hollow box with two apertures; one in which was inserted a short, funnel-shaped tube for producing the sound; the other in the top.

The latter was covered with a membrane consisting of a piece of bladder tightly stretched. A thin piece of platinum was glued upon the top of the membrane, which was connected with a wire to a screw cup, from which another wire went to a battery.

[1] "The Telephone, the Microphone, and the Phonograph," by Count du Moncel. 1879, p. 3.

[2] "The Telephone: an Account of the Phenomena of Electricity, Magnetism, and Sound," by Professor A. E. Dolbear. London, 1878, pp. 99, 102.

A platinum finger rested upon the strip of platinum, but was made fast at one end of the screw cup, that connected with the other wire from the battery.

When the sound is made in the box, the membrane is made to vibrate powerfully; this causes the platinum strip to strike often upon the platinum finger, and as often to bound away from it, thus making and breaking the circuit the same number of times per second.

If the human voice sings into the box while it is in circuit with the afore-mentioned click rod and box, the latter will evidently change its pitch as often as it is changed by the voice.

In this apparatus we have a telephone with which a melody may be produced at a distance with distinctness, but the sounds are not loud and have a thin quality.

Reiss's instrument is a good example of a simple telephone. It can produce musical tones, but not articulate speech.

In 1874 Mr. Elisha Gray of Chicago, America, endeavoured to construct a compound or multiple telephone by multiplying the receiving and discharging boxes. His success was only partial, and it was reserved for our countryman, Professor A. Graham Bell, formerly of Edinburgh, and now settled in America, to construct and exhibit the first distinctly articulating, speaking, electric telephone, which he did in 1876. The accompanying sketch (Fig. 236) gives a good idea of the arrangements proposed by Mr. Elisha Gray. The sending and receiving parts of the instrument are both depicted in an interesting way.

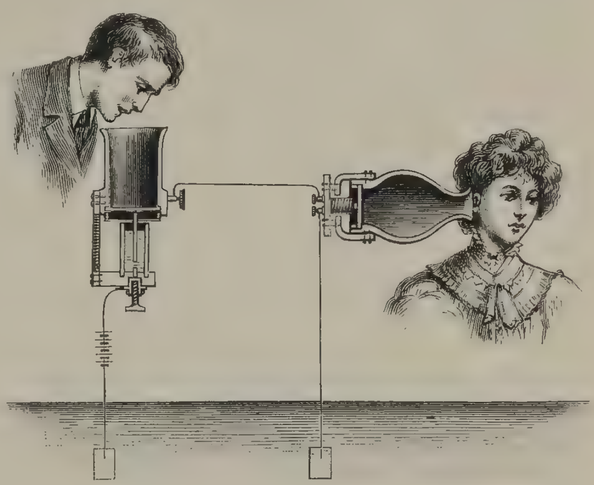


FIG. 236.

§ 247. Professor A. Graham Bell's Telephone.

Bell's telephone (Fig. 8, Plate cxliii.) was exhibited at the Philadelphia Exhibition in 1876, and produced a profound sensation in scientific circles. It was spoken of as "the wonder of wonders."

Bell's great invention was no random discovery. "Thoroughly conversant with the acoustic researches of Professor Helmholtz, and keeping in mind the complex forms of air vibrations produced by the human voice, he attempted to make these vibrations produce compound pulsations in an electric current in the manner analogous to the electric interrupter.

"Observing that membranes when properly stretched can vibrate to any kind of sound, he sought to utilise them for this purpose. So did Reiss, but Reiss inserted the vibrating membrane into the circuit, which was a mistake, as the electric current should not be broken, but only made to pulsate or throb, as it were.

"This was effected by causing a piece of iron to vibrate by means of sound vibrations in such a manner as to affect an electro-magnet and *induce* corresponding electrical pulsations." [1]

Professor A. E. Dolbear illustrates the arrangement (Fig. 6, Plate cxliii., p. 863), and gives the following explanation :—

A membrane of gold-beaters' skin was tightly stretched over the end of a speaking tube or funnel; on the middle of this membrane a piece of iron was glued. In front of this piece of iron an electro-magnet was so placed that its poles were opposite to it but not quite touching it.

When the voice caused the gold-beaters' skin with the iron affixed to it to vibrate, an interrupted or alternating current was set up between the iron and the electro-magnet, with the result that the identical vibrations communicated by the voice could be transmitted and repeated by means of insulated copper wires many miles away. The arrangement necessitated the employment of an electro-magnet, a battery, long stretches of wire, and a receiver at the extreme end of the wire. Given these, the human voice, with all its peculiarities, could be transmitted and recognised at quite extraordinary distances.

In order to increase the volume of sound, when from any cause weak or feeble, Mr. Hughes, in 1878, invented the microphone, a term derived from two Greek words, *μικρός*, small, and *φωνή*, voice, sound.

"The instrument is based on the fact that when substances possessing little electrical conductivity are placed in the course of an electric current, the conductivity of the system is much increased by even the very smallest amount of pressure. The instrument has various forms, but in most of them one piece of charcoal is held loosely between two other pieces in such a manner as to be affected by the slightest vibrations conveyed to it by the air

[1] "The Telephone," by Professor A. E. Dolbear, p. 110.

or by any other medium. The two external pieces are placed in connection with a telephone, and when the ear is placed at the earpiece of the telephone the sounds caused by a fly walking on the wooden support of the microphone appear as loud as the tramp of a horse. By suitable arrangements the sounds of the human voice conveyed from a distance by the telephone can be made audible in every part of a hall."[1]

The term telephone is obtained from the Greek words τῆλε, afar, and φωνή, voice, sound. It means, literally, far-off voice, or voice at a distance, and is applied to an instrument or apparatus for the transmission of sound to a distant point.

"The word is generally restricted to devices for the transmission of articulate speech by the agency of electricity. The process consists essentially of the transmission of electric impulses which agree in period and phase with atmospheric waves produced by sound. These in turn, by means of an electro-magnet, cause vibrations of a plate or membrane, which agitate the air in a manner similar to the original disturbance, and thus reproduce the sound. As in telegraphy, a telephonic system includes a transmitter, a conducting wire, and a receiver. In the magneto-electric telephone the transmitter and receiver are identical. A thin iron disc is placed very near, but not quite touching, the end of a small bar of steel permanently magnetised, about which is wound a coil of thin insulated wire. One end of this wire is connected with the earth and the other with the line. The sound waves produce vibrations in the iron disc, and as the magnetic field is thus subjected to rapid alterations, currents of electricity are induced, which are transmitted through the line. At the receiving end corresponding changes in the magnetism of the bar of the receiving instrument produce similar vibrations in the iron disc near it, which, in turn, produce sound waves. When the Bell telephone, a representation of which is given at Fig. 8, Plate cxliii., p. 863, is used as a transmitter, the sounds are directed towards the mouthpiece, through a hole in the centre of which the vibrations impinge on the diaphragm. The consequent vibrations of the diaphragm close to the end of the magnet induce currents in the coil, which are transmitted to the line wires through the terminals. When the instrument is used as a receiver, the pulsatory currents passed through the coil cause the diaphragm to vibrate and give out sounds, which are heard by putting the mouthpiece to the ear. Better results, however, are obtained by the use of a different form of transmitter, many varieties of which have been invented. In that most commonly used the motions of the diaphragm cause variations in the strength of a current flowing from a battery through the primary wire of an induction-coil. These variations cause corresponding induced currents to flow through the secondary wire, which is connected with the line. They are generally due to variations of resistance resulting from variations in pressure in carbon, as in Edison's transmitter (called *carbon telephone*), or in surface contact when hard carbon is used, as in Blake's transmitter. In the latter (Fig. 9, Plate cxliii.) the sounds are directed to the mouthpiece, which causes the vibrations of the air to impinge on the diaphragm, on the back and at the centre of which rests the point of a spring carrying a small spherical-shaped piece of platinum, which presses against a carbon block. The current, passing through the primary of the induction-coil, passes through the contact between the platinum and the carbon, and variations in the resistance of this contact, due to the vibrations of the diaphragm, cause currents to be induced in the secondary of the coil which are sent into the line circuit. Any form of microphone may be used as a telephone transmitter."[2]

REFLEX ACTION, INSTINCT, AND REASON

Many attempts have been made of late years to distinguish between reflex action, instinct, and reason, but these have for the most part failed, owing to the fact that the one merges into the other by insensible gradations. Indeed there are good grounds for believing that they are parts of one and the same thing, and are due to developments of the nervous system which differ less in kind than in degree.

Webster defines so-called reflex action as follows: (*a*) action directed back; (*b*) produced in reaction; (*c*) physiology—of, pertaining to, or produced by, stimulus or excitation without the necessary intervention of consciousness.

Instinct is defined by Whately and Sir William Hamilton in nearly identical terms.

According to Whately: It is a blind tendency to some mode of action, independent of any consideration, on the part of the agent, of the end to which the action leads.

According to Sir William Hamilton: It is an agent which performs blindly and ignorantly a work of intelligence and knowledge.

Dr. Johnson defines reason as the power by which man deduces one proposition from another, and proceeds from premises to conclusions.

[1] "Century Dictionary," article "Microphone."

[2] "Century Dictionary," article "Telephone."

The definitions given of reflex action and instinct are largely contradictory.

I shall endeavour to show, in the course of my observations further on, that it is impossible to draw a hard and fast line between so-called reflex action and instinct on the one hand, and between instinct and reason on the other. They are all parts, in varying degree, of one and the same thing. They all involve, in a greater or less degree, consciousness and intellect either in the individual or in the Maker of the individual.

According to Mr. Romanes, one of the recent authorities on "Animal Intelligence,"[1] so-called reflex action is "a non-mental operation of the lower nerve centres which leads to movements only in appearance intentional. . . . Objectively considered, the only distinction between adaptive movements due to reflex action and adaptive movements due to mental perception, consists in the former depending on inherited mechanisms within the nervous system being so constructed as to effect *particular* adaptive movements in response to *particular* stimulations, while the latter are independent of any such inherited adjustment or special mechanism to the exigencies of special circumstances. . . . The lower down we go in the animal kingdom, the more we observe [so-called] reflex action, or non-mental adjustment, to predominate over volitional action, or mental adjustment. That is to say, the lower down we go in the animal kingdom, the less capacity do we find for changing adjustive movements in correspondence with changed conditions."

With regard to instinct Mr. Romanes says: "Few words in our language have been subject to a greater variety of meanings than the word instinct. In popular phraseology, descended from the Middle Ages, all the mental faculties of the animal are termed instinctive, in contradistinction to those of man, which are termed rational."

Mr. Romanes distinguishes between so-called reflex action and instinct as follows: "Reflex action," he observes, "is non-mental, neuro-muscular adaptation to appropriate stimuli: but instinctive action is this and something more; there is in it the element of mind. In particular cases of adjustive action we may not always be able to affirm whether consciousness of their performance is present or absent; all we can say of such cases is that if the performance in question is attended with consciousness it is instinctive, and if not it is reflex. . . .

"Instinct involves mental operations, and by this feature it is distinguished from reflex action."

As regards reason Mr. Romanes remarks (p. 14): "Sometimes it stands for all the distinctively human faculties taken collectively, and in antithesis to the mental faculties of the brute; while at other times it is taken to mean the distinctively human faculties of intellect. . . . More correctly, the word reason is used to signify the power of perceiving analogies or ratios, and is in this sense equivalent to the term 'ratiocination,' or the faculty of deducing from a perceived equivalency of relations. . . . It is notorious that no distinct line can be drawn between instinct and reason. Whether we look to the growing child or to the ascending scale of animal life, we find that instinct shades into reason by imperceptible degrees."

Mr. Romanes, like his predecessors, has not succeeded in establishing valid distinctions between so-called reflex action, instinct, and reason. On the contrary, he is bound to admit that "it is often difficult, or even indeed impossible, to decide whether or not a given action implies the presence of the mind-element—that is, conscious as distinguished from unconscious adaptation. In particular cases of adjustive action we may not always be able to affirm whether consciousness of their performance is present or absent. Whether or not a neural process is accompanied by a mental process, it is in itself the same. The advent and development of consciousness, although progressively converting [so-called] reflex action into instinctive, and instinctive into rational, does this exclusively in the sphere of subjectivity; the nervous processes engaged are throughout the same in kind, and differ only in the relative degrees of their complexity. . . . It is notorious that no distinct line can be drawn between instinct and reason—whether we look to the growing child or to the ascending scale of animal life, we find that instinct shades into reason by imperceptible degrees."[2]

Mr. Romanes here breaks down the distinctions which he seeks to set up between so-called reflex action, instinct, and reason. He unwittingly shows that the one merges and glides imperceptibly into the other, and that "the nervous processes engaged are throughout the same in kind, and differ only in the relative degrees of their complexity."

It could not be otherwise. Nerve substance and nerve action when present are essentially the same. It is a question not of kind but of degree. When nerve substance and nerve action, in the ordinary sense, are not present, as happens in plants and in the lowest animals, there can scarcely be a doubt that their homologues exist in an undifferentiated or non-visible form. It is not otherwise possible to explain the purposive movements of many plants, and of multitudes of rudimentary animals with no visible nervous systems. A study of the movements of insectivorous plants and of innumerable low animal forms must convince every unprejudiced observer that they are

[1] "International Scientific Series," vol. xli. 1898, p. 3, &c.

[2] Professor Virchow makes a similar statement between instinct and so-called reflex action. He maintains that no line of demarcation can be drawn between the two.

all provided with guiding powers akin to intellect, in however degraded a form. They are endowed with a capacity for feeling and knowing, and, within limits, remembering and acting spontaneously and independently, and it is impossible to determine where consciousness, and reason proper, make their appearance. As there is a progressive chain of organisms, with, here and there, larger outstanding links (types), so there is a gradual rise from incipient feeling and rudimentary knowledge to the higher intelligence as witnessed in man.

Much, if not all, the difficulty connected with so-called reflex action, instinct, and reason is due to the attempt to set up distinctions which do not exist, and to the employment of terms which do not admit of exact definition. The importation of theory into the subject has further and unnecessarily complicated matters.

A careful consideration and analysis of the definitions given of so-called reflex action, instinct, and reason respectively, will verify what is now stated. It is quite evident that so-called reflex action cannot, strictly speaking, be applied either to plants or to the lower animals where a nervous system is absent, and where, nevertheless, the actions are purposive and more or less voluntary. It is equally evident, that so-called instinct cannot be dissociated from either so-called reflex action or reason. Instinct carries with it intelligence past or present—intelligence in the thing exhibiting it, or in its progenitors, or in the Creator. Wherever there are means to ends there is, of necessity, intelligence and design.

Reason, in one form or other, is vouchsafed to many animals. It is not an exclusively human attribute. As man shares with the animals many of their corporeal traits so he shares with them not a few of his mental qualities. It does not derogate from the dignity of man to regard him as a member of the animal kingdom even from the intellectual or psychic side. A foolish hue and cry has been raised of late years as to humanising the animals, and debasing man to the level of the brute. There is, however, no need for alarm. It is possible to elevate the animals to their proper positions without unnecessarily lowering the position occupied by man. They are not to be commended who take this narrow and one-sided view of the animal kingdom.

It may be asserted without fear of contradiction, that there is no such thing as automatism in living plants and animals. Plants and animals, or the power behind and working in and through them, control their movements and destinies to quite an extraordinary extent. They are, in no sense, the playthings of circumstance. If this were so the initiative in every change and movement in plants and animals would be due to stimulation caused by externalities (in most cases dead things) and to chance, which is not the case. It is the life of plants and animals which is to be credited, in the first instance, with movement and changes which result in modification and adaptation.

Any one who has studied, as I have repeatedly been obliged to do, the movements of insectivorous plants and of animalcules and other low animal forms, will have difficulty in believing that the movements in question are other than spontaneous and purposive.

Either the insectivorous plants and the lowest animals are directly under the guidance and supervision of a First Cause, or they are endowed by a First Cause with powers which enable them to control and direct their actions to given ends, with or without a nervous system, as we know it, and with or without all that is comprehended under the term intelligence as that term is generally understood and employed. The insectivorous plants decoy, seize, and devour small insects in large numbers ; and the amœba, one of the simplest animals known, throws itself over food, which it engulfs, digests, and assimilates in a deliberate manner. These actions are purposive, and in no sense due to chance ; and whatever the mechanism by which they are effected, they are the result of intelligence, either that of the First Cause or of powers (equal to intelligence) implanted in them, for their well-being and guidance, by the First Cause.

Mr. Romanes has endeavoured to explain the movements and actions of certain of the lower and lowest animals by so-called reflex movements induced by artificial stimuli apart from consciousness, adaptive ability, the power of knowing and remembering, and in ignorance of means to ends. He regards certain of the lower and lowest animals as mere machines, devoid of a directive principle and a prey to externalities, whether of environment or stimulation. He traces the rudimentary powers which he assigns to them to heredity. In so doing he forgets that in heredity are stored up all the supposed modifications, adaptations, experiences, and reasonings, however elementary and obscure, which untold generations of individuals have accumulated during their lives.

Other animals he regards as under the influence of instinct, which, according to him, is reflex action plus consciousness and a certain degree of mental power. These he credits with conscious adaptive action antecedent to individual experience and without necessary knowledge of means to ends. The animal, according to him, is conscious, and endowed with mental power or its equivalent, but it acts blindly. It, at the same time, acts *purposively* (mark the contradiction in terms in the nomenclature employed by Romanes), and apart from experience.

Such an animal is inconceivable.

Reason or intelligence proper he reserves for the higher and highest animals, including man, where there is

volition, conscious knowledge of means to ends, the power of judging, and where advantage is taken of novel circumstances and situations apart from habit and heredity.

His distinctions and divisions, I need scarcely remark, are arbitrary, artificial, and misleading. It is never safe to consider the nervous system in parts, either anatomically, physiologically, or psychologically. Wherever a nervous system occurs it is a whole, and acts as a whole. While it is possible approximately to ascertain the volume of the nervous system, there are no means of determining its quality ; it is not possible to say definitely when or where consciousness, memory, and the power of judging and reasoning first claim attention. The higher intellectual faculties doubtless belong to man and the animals immediately beneath him, but no one can say how far the reasoning faculty descends in the scale of being.

In man there is a cerebro-spinal and sympathetic system of nerves, and these are intimately and indissolubly united to each other at numerous points. In cases of disease of the upper part of the spinal cord, paralysis of the lower half of the body (paraplegia) frequently supervenes. In such cases the lower limbs are very little, if at all, under control, and they can be made to move irrespective of the will by tickling the soles of the feet and other means. A nervous apparatus and artificial stimulation are both present in such cases, but the movements are not natural. They are abnormal and the result of disease. Originally they were voluntary in their nature, and are largely the result of education and habit. They are not simple movements, but co-ordinated, combined, complex movements. They are not such as could be produced by any one kind of stimulation. The so-called reflex movements in man and the higher animals are the outcome of a set of artificial conditions of which a diseased nervous system, an induced irritability, and extraneous stimulation are chief factors.

Granted, for the sake of argument, that so-called reflex action takes place in man and in the higher animals in a healthy state, this affords no proof that the movements of animals with nervous systems but with no brains or spinal cords are, in any sense, involuntary or reflex in their character. The evidence is all the other way. There can be no doubt that animals with rudimentary nervous systems consisting of ganglia, sensory, and motor nerves, minus brains, do move voluntarily and to given ends apart from irritability and artificial stimulation. Of these I shall adduce numerous examples presently. There can also be little doubt that animals without a nervous system, as we know it, also move voluntarily. This remark, within limits, applies even to certain plants. Wherever life and feeling are found there is, as a rule, more or less spontaneity of movement. This holds true of plants and animals provided with cilia, and where locomotion of some kind is a necessity of life.

The independent action of a portion of the nervous system, in a diseased condition in man under the influence of artificial stimulation, does not establish a *prima facie* case for the movements and actions of animals, or parts of animals, being regulated by purely so-called reflex acts.

According to prevailing views, so-called reflex action requires for its production external stimulation of some sort, and irritability of the tissues and organs said to be affected by stimulation. Now I venture to assert that, in the majority of so-called reflex acts, neither stimulation nor irritability, in the ordinary sense, is present. To take an example. The movements of the eyelids in winking are said to be reflex in their nature. The eyelids are assumed to be irritable, and the light is believed to act as a stimulus. There is, however, no proof either of the alleged irritability or of the stimulation.

The movements of winking are double rhythmic ones, the eyelids alternately opening and closing. If, however, the light, acting as a stimulus, caused the eyelids to close the one instant, it could not, by any chance, cause them to open the next. The fact that the light is present during both the opening and closing movements forbids such an assumption.

If a feint be made before the eyes the eyelids blink or wink. This is due in a large measure to education and habit. As a matter of fact the rhythmic movements of the eyelids are involuntary fundamental movements provided by nature to protect the eyes and spread the lachrymal secretions over the surface of the eyeballs, to keep them moist and clear for the purpose of seeing. While the rhythmic movements are fundamental, they are, in certain instances, partly due to education and repetition, which is the case in certain of the so-called automatic movements, such as involuntary mechanical walking, pianoforte playing, &c.

§ 248. The Alternate Propelling and Retaining Structures of the Body (Heart, Stomach, Bladder, Uterus, &c.), in Relation to so-called Reflex Action.

A flood of light is thrown upon the subject of supposed irritability, extraneous stimulation, and so-called reflex action by a consideration of what I designate the *propelling* and *retaining* or *containing* structures of the body.

These structures are fundamental, and are of the utmost consequence to the well-being of the higher animals.

They have not received the attention they deserve, and are consequently not well understood. They include

the alimentary canal, the chest and lungs, the heart and blood-vessels, the bladder, the uterus, the oviduct of the bird, &c.

Hitherto, and by common consent, the movements of these structures have been regarded as reflex in their nature. They have been considered automatic structures set in motion by extraneous stimulating substances acting on their *internal* surfaces, which are regarded as highly irritable. The food is said to be the cause of the rhythmic movements of the alimentary canal, the air of the chest movements, the blood of the cardiac movements, the urine of the bladder movements, the fœtus of the uterine movements, and the egg of the oviduct movements.

Nothing could be further from the truth. So far from the structures in question being mechanical, automatic, and set in motion by extraneous substances which act as stimuli, they are, on the contrary, fundamental, self-moving, self-adjusting structures, expressly formed to set in motion, and retain for longer or shorter intervals, the very substances which are said to inaugurate and perpetuate the so-called reflex movements. It is a flagrant example of putting the cart before the horse. A moment's reflection will convince most people that it is so. The prevailing theory wholly fails, from the fact that it regards the structures under consideration as simply propelling structures. In reality, they are also *containing* and *retaining* structures. Inherent irritability and artificial stimulation (provided they are present, which, however, I deny) might partially explain how the contents of the structures in question set them in motion; they could not possibly explain how the contents were retained for longer or shorter intervals before being expelled. The retaining and expulsive acts are diamentrically opposed to each other. The same cause could not, at one and the same time, operate in opposite directions. Further, irritability and extraneous stimulation could not possibly account for the *interrupted rhythmic character* of the movements. If irritability and artificial stimulation occasioned the contraction or closing of the structures or part of the structures at one time, they could not cause the dilatation or opening of the same structures at another time. The irritability and artificial stimulation being always present, one kind of movement only could be generated. A closing or an opening movement might be produced, but, under the circumstances, mixed closing and opening movements occurring at regular intervals—that is, rhythmic movements—could not be established.

Moreover, the object for which the structures were originally created must be kept constantly in view.

The alimentary canal was designed and formed to receive, retain, digest, and assimilate food, and, in addition, to eject waste products.

It was so formed *in utero* long before food was placed in it. It was prepared in anticipation of the function it was to discharge—that function being to receive, retain, digest, and propel food at stated intervals, by a series of peristaltic or rhythmic movements. The alimentary canal was actually made before the food, which is said to cause its movements, had entered it. In like manner, the lungs and chest were prepared in anticipation of the air with which they would come in contact after parturition. Similarly, the heart and blood-vessels were fashioned before they contained blood. The same is true of the bladder, uterus, the oviduct, and their contents. Nor does the matter rest here. The alimentary canal acts in the most purposive manner, and differently in different parts of its course. When solid food is masticated, insalivated, and swallowed, the œsophagus opens or dilates in front of the bolus and contracts or closes behind it, and so the morsel which is being ingested is forced into the stomach by a pinching wave movement. No time is lost in this process. Arrived in the stomach, the food is mixed with saliva and gastric juice to form chyme and rolled about by the inherent muscular movements of the stomach for longer or shorter periods, according to the digestibility of the food taken. It is then passed on in relays to the small intestine, where by the aid of vermicular movements it is mixed with the bile, pancreatic, and other juices to form chyle, in which condition it is ready to pass into the lymphatics and blood-vessels with a view to absorption and assimilation.

The assimilation goes on until the nutrient properties of the food are effectually extracted. The waste products are then passed on to the lower bowel and rectum, where they are generally retained for from twelve to twenty-four hours before being expelled.

The alimentary canal deals with the food as a master. It hurries it along the œsophagus, and retains it in the stomach from one to two hours or longer. It further retains it in the upper and lower bowels for periods varying from six to twenty-four hours, when what remains of it is extruded. No question of irritation or artificial stimulation can be raised. It is the alimentary canal which sets the food in motion, and not the converse. This is proved in several ways. In swallowing, the œsophagus dilates or opens before, and contracts or closes behind, the morsel which is being ingested. If it were a question of mere irritation and stimulation the œsophagus would contract or close at the point of contact—that is, in front of the bolus—which it does not. The movements of the œsophagus follow up and determine those of the bolus; each part of the œsophagus being invested with a double power, whereby it alternately opens and closes by rhythmic centripetal and centrifugal movements. These movements, as I pointed out in 1872,[1] are characteristic of all muscular action.

[1] *Edinburgh Medical Journal*, 1872.

The double opening and closing power extends to every part of the alimentary canal. It accounts for the swallowing movements of the œsophagus, the rolling movements of the stomach and the opening and closing of its sphincters, the vermicular movements of the bowel by which the food is passed on, and those of the rectum by which the detritus of the food is finally expelled. I append drawings of original dissections by myself of the muscular fibres of the œsophagus and stomach (Fig. 237, A, B, C, D, E). Elaborate dissections of the stomach were given at Plates cii. and ciii., pp. 529 and 531.

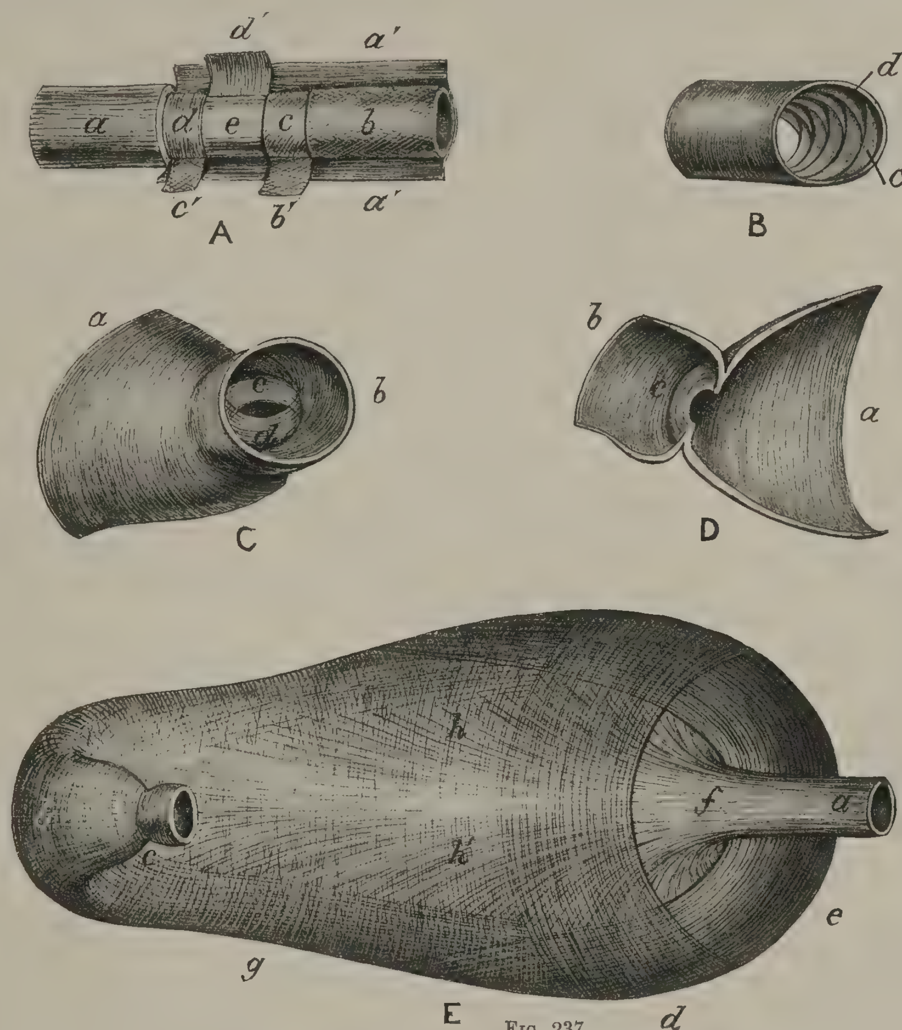


Fig. 237.

Fig. 237.—Shows the arrangement of the muscular fibres in the œsophagus, duodenum, and stomach, and especially, how the sphincters of the stomach are formed. The muscular fibres of the œsophagus of the horse are arranged in seven more or less continuous layers as in the human stomach; and the sphincters of the human stomach consist of two sets of very oblique fibres which overlap and embrace each other as in the valvulæ conniventes of the human duodenum.

A. Portion of the œsophagus of the horse. *a*, *a′*, *a′*, external longitudinal fibres; *b*, *b′*, two sets of oblique fibres beneath longitudinal fibres which cross each other spirally; *c*, *c′*, two sets of deeper and still more oblique fibres which also cross each other spirally; *d*, *d′*, transverse or so-called circular fibres still deeper, which separate the external from the internal fibres; *e*, longitudinal fibres forming an internal layer.

B. Portion of human duodenum with valvulæ conniventes (*c*, *d*) crossing very obliquely and embracing and interlocking after the manner of sphincters. Similar arrangements are seen in the interior of the œsophagus of the cat.

C. Small end of the human stomach (*a*), and the beginning of the duodenum (*b*), with the pyloric valve or sphincter (*c*, *d*) between. The aperture of the sphincter is elliptical in shape; the shape being due to the fact that the sphincter is composed of two sets of very oblique fibres (*c*, *d*), which cross each other and form loops. The same parts are seen from within in section at D—the lettering being the same as at C.

The œsophageal or cardiac sphincter is shown at E, and consists of two powerful bands of fibres (*d*, *e*) which cross each other very obliquely and enclose an elliptical space at the root of the œsophagus (*f*). The construction of the œsophageal sphincter very closely resembles that of the pyloric sphincter. The arrangement of the muscular fibres in each case is perfect for closing and opening purposes.

At E, the arrangement of the muscular fibres on the smaller curvature of the human stomach is given. *a*, External longitudinal fibres of œsophagus; *b*, longitudinal and transverse fibres of pylorus; *c*, constriction indicating position of pyloric valve—seen in section at D; *d*, *e*, two powerful bands of fibres forming the œsophageal or cardiac sphincter, which constricts on the root of the œsophagus (*f*); *g*, transverse or so-called circular fibres of stomach; *h*, *h′*, fibres which radiate from the root of the œsophagus (*f*), (the Author, 1866).

The movements of the alimentary canal are, in one sense, continuous. In another sense, they are interrupted. The food is delayed and retained in the stomach, it is further delayed and retained in the upper and lower bowel and rectum, and finally extruded at periods varying according to the nature of the food ingested and the state of the bowels.

It is quite certain that the food of itself could not induce the several movements in question. It is equally certain that the food could not insure its retention for longer or shorter intervals in different parts of the alimentary canal, and it goes without saying that the food could not produce its own ingestion, retention, and final expulsion.

The point I wish to emphasise in this connection is, that the alimentary canal performs a variety of functions, and that the food, which is supposed to act as a stimulus, cannot inaugurate or ensure the discharge of these functions. It follows, that in this particular case the theory of irritability and artificial stimulation and so-called reflex action completely breaks down.

A similar line of argument may be followed with regard to the movements of the chest and lungs; the air being erroneously considered the stimulus which causes the respiratory movements.

The air is present both during inspiration and expiration—the respiratory movements occurring some eighteen times per minute. It cannot, therefore, excite the chest and lungs to open and close alternately as they do. If it caused the chest and lungs to open the one instant, it could not possibly cause them to close the next. The same stimulus could not act in two opposite directions. As a matter of fact, the respiratory movements inhere in the chest and lungs, and are not due to either irritability, artificial stimulation, or so-called reflex action. What is true of the alimentary canal and respiratory movements is also true of the cardiac ones. The blood fills the heart and the entire vascular system. It could not, therefore, as a stimulant, cause the auricles and ventricles alternately to open and close sixty, seventy, or eighty times per minute, and produce the rhythmic wave movement known as the pulse. Here, again, the movements are inherent and fundamental. The heart is not irritable, and the blood does not act as a stimulus and induce and perpetuate its rhythmic movements. Further, the blood does not produce the pause which occurs between the opening and closing of the ventricles. Finally, the irritability and stimulation which are said to produce reflex cardiac action are wholly absent.

In the case of the bladder and uterus, similar results are observed. The urine does not act as a stimulus and produce so-called reflex acts in the bladder, neither does the fœtus act as a stimulus and produce so-called reflex acts in the uterus. The bladder retains its contents for four or five hours at a time, and ejects them by a series of vermicular wave movements at the end of that period. The uterus retains its contents for nine calendar months, when parturition supervenes. Neither in the bladder nor in the uterus do their contents produce the interrupted rhythmic wave movements. The bladder and uterus are, in a sense, more retaining than propelling structures, and their movements are certainly spontaneous and independent. They cannot for a moment be regarded as due to irritability, stimulation, or so-called reflex action.

Finally, the oviduct of the bird discharges a number of functions which cannot even be partly explained by the theory of irritability, artificial stimulation, and so-called reflex action. The egg, which it receives in an immature state from the ovary, it develops, elaborates, and transmits in its passage. The egg cannot, even by a stretch of the imagination, be regarded as a foreign body or stimulus. It is a living, innocuous thing (part of the bird itself) received by the fimbriated extremity of the oviduct when only partly formed. At first it consists only of a vitellus or yolk covered by a vitelline membrane. By a series of well-regulated rhythmic movements it is transmitted in a downward direction, and is perfected in its descent in the four compartments into which the oviduct is divided.

In the first compartment (two or three inches in length) the vitellus is soaked in a liquid which makes it more flexible and yielding; in the upper part of the second compartment (nine inches long) another membrane is added to the vitelline membrane (the chalaziferous membrane), and this, because of rotatory and progressive movements communicated to it by the oviduct, is twisted spirally in opposite directions at either end to form two fine cords, the "chalazæ." In the lower portion of the second compartment successive layers of a gelatinous albuminoid substance are provided to form the white of the egg. In the third division of the oviduct (three and a half or so inches long) three layers of tough, fibrous material are added to form the soft shell. In the fourth compartment (a little over two inches in length) the outer of the three layers forming the soft shell has calcareous salts added to it, the outer part of the soft shell being thus converted into a hard shell. The egg is now completed and ready for laying.

Delays in transmission, and at least four different sets of movements, are required to produce these several results. Thus there are (*a*) pauses or rest points in the several compartments of the oviduct; (*b*) the movements of the various secretions which add to and complete the egg; (*c*) the peristaltic movements which impel the egg

from above downwards; and (*d*) the movements of expulsion which introduce the egg into the outer world, where it is hatched or otherwise dealt with.

Few better examples of designed, vital, purposive movements can be given than are afforded by the completion and transmission of a bird's egg down its oviduct. The theories of irritability, extraneous stimulation, and so-called reflex action must each and all be abandoned. They have, there are good grounds for believing, no foundation in fact. The anatomy and physiology of the oviduct of a barn-door fowl, showing the formation and descent of the egg and the apparatus by which the egg is transmitted to the oviduct, are given at Fig. 238.

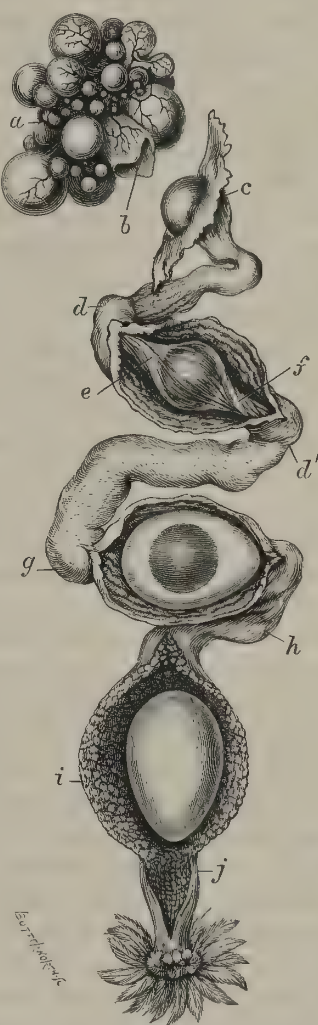


Fig. 238.—Shows ovary, oviduct, and eggs of common barn-door fowl. *a*, Ovary, with eggs at various stages of development; *b*, Graafian follicle from which an egg has been discharged; *c*, fimbriated extremity of oviduct with egg entering it; *c*, *d*, *d′*, portion of oviduct supplying egg with moisture and twisted chalaziferous membrane (*e*, *f*); *d′*, *g*, *h*, portion of oviduct engaged in providing the egg with a coating of albumen (the white of the egg); *h*, *i*, *j*, portion of the oviduct furnishing the three membranes of the egg (two soft and one hard) (after Dalton).

The viscera to which I have alluded are fundamental, vital structures, and are prepared in advance of the substances which form the so-called stimuli. They are specially fashioned to receive, retain, and transmit air, food, urine, blood, &c.; the transmission of the said substances being essential to the well-being of the individual. The viscera are the outcome of life and growth, and their movements are spontaneous and independent. The viscera cause the movements of the substances they contain; the substances do not occasion the movements of the viscera. This is no mere play upon words. It is easy to understand how a living structure receives, contains, and propels a dead substance; it is impossible to understand how a dead substance occasions its own reception, retention, and expulsion. According to accepted views, so-called reflex action is primarily due to irritability and stimulation; the organism, or part thereof, acting automatically or mechanically—that is, non-voluntarily. The life exercises no power, and the organs no function. There is no opportunity for modification, adjustment, or adaptation of any kind. The dead thing inaugurates and regulates the movements and actions of the living thing. Blind chance and fortuitous circumstances determine the internal workings and ultimate destinies of plants and animals alike, which is not according to fact. In reality all living things are superior to their surroundings. They modify and adapt themselves to environment as occasion requires, but the modification and adaptation, when they occur, are due to a First Cause, design, life, and original endowment. In other words, plants and animals are provided with powers which enable them to live, grow, reproduce themselves, and maintain their places in nature. They are, in no case, mere machines which are set in motion and kept going by irritation and chance external stimulation. On the contrary, they have in themselves that which makes them superior to every form of dead matter—the poisonous substances excepted. So-called reflex action, when applied to the more lowly organisms and to parts of the higher organisms, is more or less a misnomer. The term lends itself to mechanical views and explanations which are at once inaccurate and misleading. So-called reflex action in the higher animals, in the opinion of modern physiologists, implies the presence of sensory nerves, motor nerves, ganglia, nerve cells, irritable surfaces, and stimulation of some kind. The sense organs are said to work reflexly. Light, it is maintained, is the stimulus for the highly sensitive retina. Vibrating, sounding bodies are regarded as the stimulus in hearing, odoriferous and sapid substances are believed to be the stimuli in smelling and tasting, and tangible bodies are supposed to provide the stimuli for the skin and touch corpuscles in feeling. It is not necessary to assume reflex action in connection with any of the senses. The sense organs are expressly formed to deal with the objects of sense at first hand. The material vibrations known as light and sound directly affect the optic and auditory nerves by way of impact, as in the case of extraneous substances touching the skin, and the odoriferous and sapid particles touch the olfactory and gustatory nerves in a more or less liquid form. There is nothing mysterious in the matter of seeing, hearing, smelling, tasting, and touching. The brain and spinal cord, when intact and healthy, with their sensory and motor nerves, act directly and at first hand. If a sensation is passed on from the skin or sense organs it is at once interpreted by the ganglia of the cerebro-spinal system. Voluntary co-ordinated movements may or may not follow. These movements, at first voluntary, may become involuntary if often repeated. Many of the so-called reflex movements are voluntary at the outset and become involuntary by repetition. Even the involuntary rhythmic move-

ments exhibit traces of volition and intelligence—namely, the intelligence of the First Cause. The rhythmic movements are purposive; they are means to ends; they are spontaneous, fundamental, and bespeak a Designer. Where muscles and nerves and co-ordinated movements occur they are traceable, directly or indirectly, in every case to intelligence. The end is involved in the beginning structurally and functionally. Nature does not work in a roundabout way. Living things are fashioned to deal directly with everything outside of themselves.

So-called reflex action, if it occurred, would be at best a clumsy form of roundabout procedure. The power of initiating and carrying out movements and changes of all kinds inheres in plants and animals apart from irritability, artificial stimulation, and so-called reflex action. How otherwise could digestion, absorption, assimilation, secretion, excretion, reproduction, &c., take place? Plants and animals seize food, provide gastric and other juices for its digestion, assimilate it, and throw off the detritus or waste materials. The food is obtained directly, apart from so-called reflex action. Living things practically throw themselves upon food because they require it. The food does not throw itself upon them and stimulate them into activity reflexly. There is no need for indirect reflex movements even in the higher animals. In the case of the lowest animals and plants, where neither nerves, ganglia, nor muscles are present, the movements connected with digestion, assimilation, secretion, and excretion are effectively performed. If, however, the supposed machinery of so-called reflex action can be dispensed with in any case, it raises the question as to whether or not so-called reflex action is a reality.

Personally, I am more and more disposed to discredit so-called reflex action and the mechanical explanations given of vital functions, and to fall back upon life and fundamental endowment as conferred by a First Cause. I cannot admit that all living things are irritable, and that stimulation in some form must precede action. In other words, I do not believe that plants and animals, or any part of plants and animals, are to be regarded as automatic. On the contrary, I am fully persuaded that they are, in every instance, masters of the situation, and that in virtue of original endowment, however acquired, they are placed for the most part on the high level of voluntary agents in the universal or cosmic sense. It has been said that the light acts as a stimulus to the iris, and occasions the contraction or dilatation of the pupil or aperture of the eye *by indirect or so-called reflex acts*; that it causes the pupil to contract if there be much light, and to dilate, open, or expand if there be little light—the light admitting itself into, and excluding itself from, the interior of the eye as if it were a self-acting, intelligent agent. It is contended that the inanimate or dead light, if one may so say, at once causes and regulates the movements of a living structure—the iris. It would be more correct to affirm that the living structure deals with and regulates the amount of light admitted to the interior of the eye *by direct acts*.

As a matter of fact, the light is the correlate or natural objective of the iris; it is that particular something which the iris is specially constructed to control and regulate. Similar remarks may be made of all living structures. They have all their counterparts or objectives. Living structures are created to perform certain functions: they are in every instance intended to act upon something outside of themselves, and that something is the correlate, co-ordinate, or natural objective. Without the correlate the structure would avail nothing. It would cease to be a means to an end. It would have no *raison d'être*, and would stultify its existence. The air is the correlate of the lungs, the blood of the heart, the food of the alimentary canal, the fœtus of the uterus, resisting substances of the muscles, feeling and thought of the nervous system and brain, physical waves of light of the eye, bodies vibrating in space of the ear, odoriferous particles of the nose, sapid substances of the mouth, external objects of the skin, and so on. In like manner the land is the correlate of the small foot, the water of the expanded fish tail, and the air of the greatly extended wing.

Examples of correlates might be multiplied indefinitely. For example, grasses and plants are the objectives of the teeth of herbivora: animals of the teeth of carnivora; and plants and animals of the teeth of omnivora. Milk is the objective of the toothless babe, secretions and excretions of the secretory and excretory glands, &c.[1]

In a complex animal there is division of labour, and each structure is entrusted to perform a certain function either separately or in conjunction with all the other structures. While the several structures may, and do, act separately up to a point, they also act collectively and in concert. It is their separate and collective or combined action which gives to the higher animals their extraordinary power of dealing with everything in detail, and which makes them superior to their surroundings. A complex animal, when healthy, acts as a whole as perfectly as if it were a piece of undifferentiated protoplasm. Differentiation means a departure from simplicity, a specialisation of structure and of function, a division of labour. The division of labour can only be carried out by the formation of more or less independent, self-acting structures; these structures being part of the original animal, growing and developing as the animal grows and develops, and having their correlates or objectives from the beginning or as soon as they are properly formed. The structures in question are in no case chance products. They are not formed

[1] Theologians regard immortality as the correlate of the craving of the human race for a continued existence. They say that the craving must have an objective after death, otherwise it would not be felt.

by externalities or extraneous stimulation. The light does not make the eye, sound the ear, the ground the foot, the water the fish tail, or the air the wing. The structures are constructed to act at first hand and directly. There is no need to assume that any of them act indirectly or reflexly. The iris is expressly formed to admit and measure the amount of light admitted into the interior of the eye. It consists of radiating and circular muscular fibres ; these fibres being mixed up structurally and acting together. The muscular fibres of the iris are endowed with the double movement (centripetal and centrifugal) which I claim for all muscles. In virtue of the centripetal movement, the iris diminishes its central aperture or pupil ; by means of the centrifugal movement it increases it. It is quite clear that if the light acted as a stimulus to the iris and caused the *contraction* of the pupil it could not also cause its *dilatation*. The same light could not produce diametrically opposite results. In reality the movements of the iris are involuntary, rhythmic movements, and these, wherever they occur, are, as I have already explained, original endowments, and in no sense dependent on irritability, extraneous stimulation, or so-called reflex action. The eye and the iris are expressly formed to deal with the light and the objects which the light reveals, but the light and the objects do not cause the eye to see or the iris alternately to contract and dilate.

In giving this explanation of the movements of the iris, I am well aware that the anatomists and physiologists of the present day assert that the radiating and circular fibres of the iris form separate layers which are quite distinct, and that when the fibres of the circular layer contract, close, or shorten, they forcibly drag out and elongate the fibres of the longitudinal, radiating layer ; while the fibres of the radiating layer, when they contract, close, or shorten, forcibly drag out and elongate the fibres of the circular layer. Careful dissections of the iris of the ox have convinced me that such a position is untenable. The radiating and circular fibres are, I find, so united and geared to each other that a separate, independent, alternating action of the two sets is impossible. The two sets of fibres in question act together and consentaneously, and are endowed with fundamental centripetal and centrifugal movements as in the hollow viscera. If it were otherwise we would have two sets of muscles virtually acting in opposite directions at one and the same time, and so preventing the characteristic movements of the iris. The peculiar movements referred to can only be produced by combined centripetal and centrifugal movements occurring in the circular and radiating fibres respectively.

The centripetal and centrifugal movements of the iris, as well as of other involuntary and voluntary muscles, such as those of the smaller arteries, the intestine, stomach, bladder, uterus, diaphragm, heart, limbs, &c., can be readily explained (see Plates lxxxiii. and lxxxiv., pp. 320 and 322).

As I pointed out as far back as 1872,[1] the involuntary muscles are the precursors or parents of the voluntary ones, the latter being slightly more differentiated than the former. Both originate in cells, and both act rhythmically by centripetal and centrifugal movements. The rhythms are most marked and persistent in the involuntary muscles, but the voluntary muscles, when they act, display essentially rhythmic movements ; the movements extending in waves from what are practically fixed points. When a muscle shortens in the direction of its length, it elongates in the direction of its breadth, and *vice versâ ;* there being no diminution of bulk. What holds true of an entire muscle also holds true of its sarcous elements or ultimate particles. Indeed the change of shape in the sarcous elements determines the change of shape in the muscle itself, and it is with the sarcous elements we have primarily to deal in explaining the action of muscle as a whole.

When a limb is at rest—that is, neither flexed nor extended—the sarcous elements of the muscles assume a cube-shaped form which is at once fundamental and typical. When the limb moves by ever so little, the cube shape is at once modified ; the sarcous elements elongating and arranging themselves in opposite directions and at right angles in the flexor and extensor, abductor, and adductor, pronator and supinator muscles respectively (Plate lxxxiii., p. 320).

The limb when in action moves on either side of a given line ; the line corresponding with the position of rest. When muscles are not acting they enjoy absolute repose. They are not in a condition of semi-activity or on the stretch, as implied by the term *tonus*. The position of rest in a limb, as explained, is the partial or semi-flexed condition. In extreme flexion and extension the sarcous elements are in their most active states (Plate lxxxiii.). A similar boundary, as regards the activity and non-activity of the sarcous elements, is witnessed in the smaller arteries, the intestine, and in all the hollow viscera. In the smaller arteries there is what may be designated the median or normal calibre of the vessel (the position of rest for the sarcous elements). Any increase or diminution of the calibre can only be produced by the activity and change in shape of the sarcous elements (Fig. 66, p. 318). This point is readily illustrated by a transverse section of the left ventricle of the heart of the bird and mammal, as seen in Figs. 239, 240, and 241, p. 884.

In Fig. 239 the circle (*a*) represents the position of rest for the sarcous elements when the ventricle is half open ; the circle (*b*) their period of activity when the ventricle is closed ; and the circle (*c*) their period of activity when

[1] "The Physiology of the Circulation in Plants, in the Lower Animals, and in Man." (*Edinburgh Medical Journal*, 1872–73.)

the ventricle is open. The arrows indicate the centripetal and centrifugal movements by which the closing and opening of the ventricle are effected. The opening and closing movements are further illustrated, on a slightly reduced scale, at Figs. 240 and 241, Fig. 240 indicating the centrifugal movement and Fig. 241 the centripetal one.

The left ventricle is completely closed during the systole or contraction of the ventricle; and the left auricle, because of its thin walls, has no power to force blood into it. It therefore opens spontaneously to receive the blood. The opening and closing movements of the left ventricle are vital in their nature. This is a point of great importance, as showing that the heart works independently and apart from irritability, stimulation (supposed to be supplied by the blood), and so-called reflex action.

Muscles, as indicated, have their periods of activity and of repose; they cannot act continuously, neither can they act instantaneously. They require a certain time to leave their position of rest. If by any chance muscles

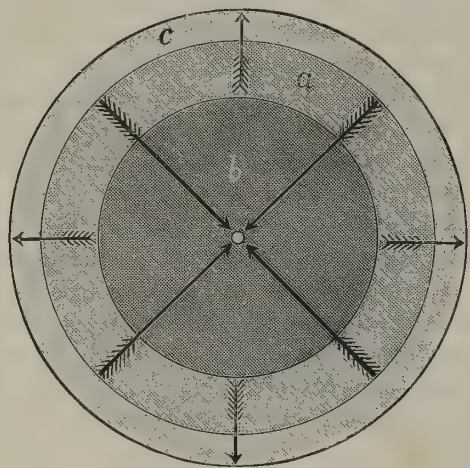


Fig. 239.

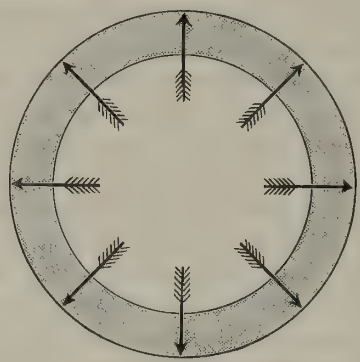


Fig. 240.

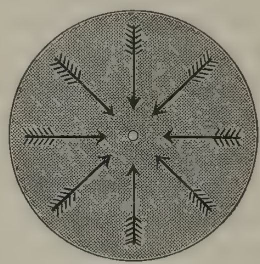


Fig. 241.

Fig. 239.—Shows the centripetal or closing and the centrifugal or opening movement (*vide* arrows) of the muscles and sarcous elements in the left ventricle of the heart of the mammal. *a*, Zone of rest; *b*, zone of contraction or closing; *c*, zone of dilatation or opening (the Author).

Fig. 240.—Shows the centrifugal, relaxing, or opening movements (*vide* arrows) of the muscles and sarcous elements of the left ventricle of the heart of the mammal (the Author).

Fig. 241.—Shows the centripetal, contracting, or closing movements (*vide* arrows) of the muscles and sarcous elements of the left ventricle of the heart of the mammal (the Author).

are taken unawares and act instantaneously they are apt to snap and rupture. In voluntary muscles, a certain period must elapse between the receipt of the motor impulse and the movement. This period corresponds with the time required for the motor impulse to travel from the brain to the muscles concerned, and it can be measured. The rate of nerve transmission is, roughly speaking, the speed attained by a first-class English racehorse, namely, a mile in little over two minutes.

The simplest muscular arrangements are those met with in the small arteries, in the intestine, in the iris, and in the muscles moving the eyeball; the most complex are those witnessed in the stomach, bladder, uterus, diaphragm, the ventricles of the mammalian heart, and the voluntary muscles in their grouped combinations, and where they invest ball and socket joints, as at the shoulders and hips.

In the diaphragm (Figs. 45 and 46, p. 281) the muscular fibres run in radiating, curved lines from the central tendon. If projected they would intersect in every direction. The diaphragm is a dome-shaped muscle, and may aptly be compared to a half stomach or bladder. It is endowed with centripetal and centrifugal movements like the other involuntary muscles. When it contracts or shortens its muscular fibres, it flattens itself and increases the capacity of the thorax at the expense of the abdomen: when it relaxes or elongates its muscular fibres it assumes a dome shape, and increases the capacity of the abdomen at the expense of the thorax. The closing or contracting and the opening or relaxing movements are altogether independent of each other; the one does not cause the other. Here there can be no suspicion of antagonism in muscular action. There are no flexor or extensor, abductor or adductor, pronator or supinator muscles present forcibly to drag each other out: neither can elasticity be credited with the relaxing, dilating movement.[1] The diaphragm is self-acting. It is an all-important muscle in respiration, and is fundamentally endowed with the double power of alternately relaxing or opening and contracting or closing.

[1] According to prevailing views the diaphragm can only contract: its relaxation being due to elasticity and the recoil upwards of the abdominal viscera, which are said to be pressed down when the diaphragm contracts.

This it does rhythmically by vital movements traceable to its substance and to its nerve supply. The action of the diaphragm cannot be referred to so-called reflex movements, to inherent irritability, or to extraneous stimulation.

The heart, on the whole, affords the best example of a spontaneous, independent, rhythmic, prime mover which acts at first hand or directly, and apart from irritation, stimulation, or so-called reflex action. It is one of the fundamental, specially constructed organs which are absolutely essential to life in the higher animals, and if it had to perform its work by indirect, roundabout, unmechanical methods it is all but certain that it would be unequal to the herculean task it is called upon to perform.

In the diaphragm the muscular fibres, as pointed out, run at right angles, and at every degree of obliquity, as in the left ventricle of the heart, and in the hollow viscera generally. All these structures display to perfection the best possible arrangement for the wonderfully effective centripetal and centrifugal movements to which allusion has been made so frequently. The diaphragm and hollow viscera are constructed on mathematical principles, so as to secure the maximum of strength with the minimum of material. They are fundamental, powerful organs, and on their integrity life, in the higher animals, largely depends. They are capable of acting as prime movers, apart from irritability, stimuli, and so-called reflex arrangements, which are believed to depend on stimuli.

The involuntary muscles may be arranged according to an ascending scale. First, there are the so-called circular (really spiral) involuntary muscular fibres found in the smallest arteries : secondly, the circular and longitudinal muscular fibres witnessed in the larger arteries and in the intestines : thirdly, the circular, longitudinal, and oblique muscular fibres found in the œsophagus, stomach, bladder, uterus, diaphragm, ventricles of the heart, &c. The

FIG. 242.—Photograph of frozen section of the right and left auricles and of the left ventricle of the heart in the human subject, showing the extreme tenuity and weakness of the walls of the right and left auricles as compared with the great thickness and power of the walls of the left or principal ventricle. *a*, Cavity of right auricle ; *b*, cavity of left auricle ; *c*, wall of right auricle in the relaxed condition ; *d*, *e*, wall of left auricle in the relaxed condition ; *f*, wall of left ventricle during the systole or firmly contracted state, when it is a solid muscular mass ; *g*, pulmonary vein ; *h*, portion of aorta. The point of supreme importance in this figure is the relative thickness of the walls of the left auricle (*d*, *e*) and those of the left ventricle (*f*).

The conclusion at which I have arrived, after the examination of hundreds of hearts, is that the left auricle has no power whatever forcibly to open up or distend the firmly contracted left ventricle, and that the left ventricle, from the nature of things, must open spontaneously and of its own accord (the Author).

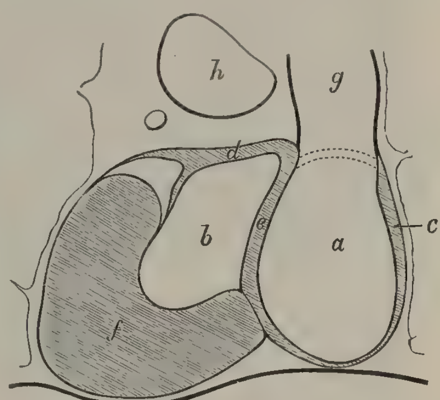


FIG. 242.

ventricles of the heart consist, according to my dissections, of no less than seven layers of muscular fibres which are continuous upon themselves at the apex and base of the ventricle, and are arranged in spiral figure-of-8 loops —some running in a nearly vertical direction, some nearly transversely, some slightly obliquely, and some very obliquely (Plate xcvii., p. 511). As all the muscular fibres cross each other they form a very complex and highly intricate network (Plate xcviii., p. 513). In reality the muscular fibres of the ventricles of the heart are arranged on the girder bridge principle, where stays and struts run in a variety of directions, and give mutual support, and secure a maximum of strength with a minimum of material. The same is true of the hollow viscera as a class. The muscular fibres of the ventricles, as stated, are continuous upon themselves, and have neither origins nor insertions. There can, consequently, be no question of flexors and extensors, abductors and adductors, pronators and supinators, and antagonistic muscular action of any kind. The several muscular layers are also connected with each other by muscular slips, cellular tissue, blood-vessels, nerves, lymphatics, &c., and of necessity act together and simultaneously during both the closing or systolic, and the opening or diastolic movements of the ventricles. The muscular fibres of the auricles, which have a simpler arrangement, also act together and simultaneously. The two auricles close when the two ventricles open, and *vice versâ*. The outstanding feature between the auricles and ventricles is the comparative thickness of the auricular and ventricular muscular walls. The wall of the left auricle is, according to my observations, little more than the sixteenth of an inch in thickness, whereas that of the left ventricle is nearly half an inch. This is a fact of great significance in the action of the heart, for, according to my observations, the left auricle cannot possibly, even by its most vigorous contractions, forcibly open up or dilate by its contained blood the firmly closed left ventricle. This view is strengthened, and in a manner confirmed, by the further fact, that the left ventricle, when firmly closed at the end of the systole, forms a solid muscular mass, into which the blood (the supposed stimulating and distending medium) cannot be made to enter. The difference in the thickness of the walls of the left auricle and left ventricle is given at Fig. 242, which is taken from a photograph of

my dissection. Neither is the left ventricle opened or dilated by the aid of elasticity, believed by some to inhere largely in the muscular fibres. During my five years' term of office as pathologist to the Royal Infirmary of Edinburgh, I have again and again found the left ventricle firmly closed and forming a solid muscular mass when the *rigor mortis* had passed off. This could not possibly have happened if the supposed elastic properties of the muscles are the real and only cause of the opening or dilating movement. Elasticity is, at best, a mere mechanical property, and it would certainly have asserted itself when the walls of the left ventricle lost their rigidity and became more or less flaccid : this, however, it never did. The left ventricle, as firmly closed in systole, is seen in a photograph of a frozen section of the chest of a cadaver (Fig. 243). This figure shows the marked discrepancy in the thickness of the left auricular and ventricular walls. The only logical inference is that the left ventricle opens of its own accord by centrifugal movements.

The prevailing belief is that the left auricle, by the vigorous contraction of its thin walls, forcibly opens the thick, powerful, firmly closed walls of the left ventricle : further, that the left ventricle, when it contracts or closes, forcibly opens the left auricle through the blood contained in ten or more feet of arteries, capillaries, and veins. This theory outrages all mechanical principles, and need not be seriously refuted. The only explanation which meets the requirements of the case is that which attributes to the auricles and ventricles the double power of alternately opening and closing spontaneously by vital centrifugal and centripetal movements ; the auricles opening when the ventricles close, and *vice versâ*. There are many facts which conduct inevitably to this conclusion, and which may be briefly enumerated.

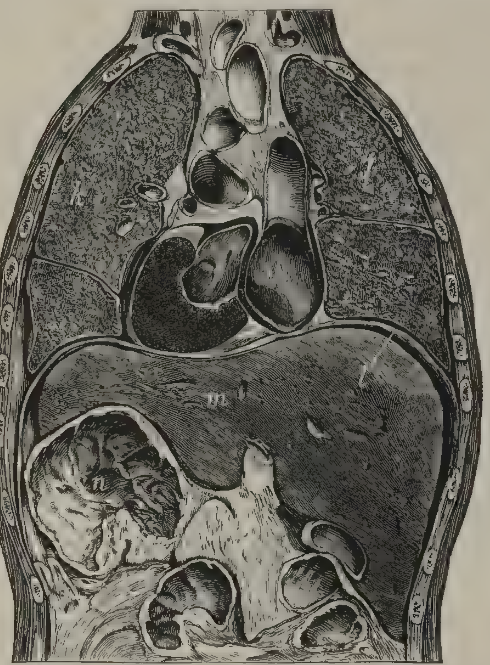


Fig. 243.—Photograph of section of the frozen human body, showing the cavities of the thorax and abdomen with their contained viscera in position. Seen from behind. *j*, Right lung ; *k*, left lung ; *l*, diaphragm ; *m*, liver ; *n*, stomach. The heart occupies a central position between the right and left lungs, and its under surface is in contact with the upper surface of the diaphragm. Note the marked difference in thickness of the auricles and the left ventricle. The heart is enlarged at Fig. 242, the better to show the great discrepancies in question (the Author, 1867).

1. The great disparity in the thickness of the left auricular and ventricular walls.

2. The living left ventricle opens and closes regularly for a considerable time after the left auricle, and its contained blood, have been removed.

3. The left ventricle beats when its nerves have been poisoned, which shows that the power of opening and closing inheres in its muscular fibres.

4. The heart of the chick beats regularly and rhythmically while it is yet a mass of nucleated cells, and before it contains either muscles or nerves, and even before it contains blood.

5. The heart of the lobster is composed of a single compartment, but it opens and closes spontaneously and regularly in the absence of adequate antagonistic structures, and in spite of its supposed elastic properties.

6. The existence of opening and closing, spontaneous, rhythmic movements is not confined to the heart and other structures of the higher animals. They are found in the most rudimentary animals, and even in plants, where no trace of muscles or of a nervous system can be detected.

7. They occur in the plant *Volvox globator*, and in the amœba, one of the most rudimentary and simplest of animals. They occur in several other plants and low animal forms.

8. If, however, spontaneous, rhythmic, opening and closing movements occur in plants, and in the most rudimentary animals, where no trace of muscles and nerves can be detected, we are forced to conclude that these very remarkable movements *are not reflex in their nature*, and are not due to irritability, excitability, or to extraneous stimulation. We can only infer that they are inherent fundamental movements, which are, in some mysterious way, necessary to the life of the individuals exhibiting them.

The importance of the spontaneous, rhythmic, opening, and closing movements cannot be over-estimated when considering organic movements as a whole. They are give and take movements—movements in opposite directions —and are intimately connected with the seizure of food, and the dismissal of waste products ; with the air in breathing ; with the blood in the circulation ; with the ovum in reproduction ; with the ground in walking ; with the water in swimming ; and with the air in flying. The give and take movements are at the root of everything in organic life.

What has been said regarding the movements of the arterioles, alimentary canal, iris, stomach, bladder, uterus,

diaphragm, and heart applies with equal cogency to the movements of the voluntary muscles as seen in the so-called flexors and extensors, the abductors and adductors, the pronators and supinators, &c. All these display independent, co-ordinated, rhythmic, centripetal and centrifugal movements, apart from irritability, extraneous stimulation, and so-called reflex action.

One of the simplest examples of voluntary muscular arrangement is met with in the muscles moving the eyeball. The muscles in question are nearly straight, and arranged in two symmetrical sets; one set being placed above and below the eyeball (superior and inferior recti), the other to its outer and inner sides (external and internal recti). Each set forms an interrupted muscular cycle, the sarcous elements of one half of which close or contract when those of the other half open or relax, and *vice versâ*. In virtue of this simple arrangement the eyeball can be moved upwards or downwards and inwards or outwards at will. To the two sets of muscles referred to, another is to be added, namely, the oblique rectus, which works round a curious pulley at right angles to the others, and confers on the eyeball the power to rotate. The simple distribution of muscles to which attention is directed is seen to advantage at Fig. 244. The eye, in virtue of its muscular arrangements, can look in every direction—upwards, downwards, outwards, inwards, and obliquely. The movements are voluntary, but the eyes have to be trained to look in various directions. An infant has to learn to use

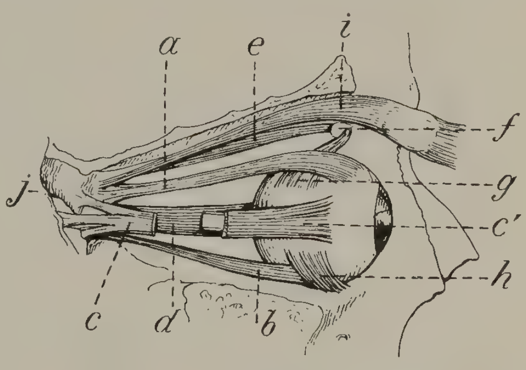


Fig. 244.

Fig. 244.—Muscles of the right eyeball (human). Shows how the eyeball can be made to move upwards, downwards, outwards, and inwards, and how it can be made to rotate upon its axis. *a*, Superior rectus muscle; *b*, inferior rectus muscle; *c*, *c′*, external rectus muscle cut across; *d*, internal rectus muscle. These four muscles act in pairs. When the superior rectus contracts or shortens the inferior rectus relaxes or elongates, with the result that the eyeball is pulled upwards. When the inferior rectus muscle contracts or shortens the superior rectus relaxes or elongates and the eyeball is pulled downwards. The recti can combine to produce diagonal movements of the eyeball, in which case it is made to move upwards and inwards, upwards and outwards, downwards and inwards, or downwards and outwards. The same thing happens in the external and internal rectus muscles when the eyeball is pulled outwards or inwards. The rotation of the eyeball on its axis is produced by the superior oblique muscle (*e*), which works round the corner by means of a pulley (*f*). The superior and inferior oblique muscles (*g*, *h*) cause the eyeball to rotate at pleasure. The superior oblique, acting alone, rotates the globe so as to carry the pupil outwards and downwards to the lower and outer side of the orbit; the inferior oblique rotating the globe in such a direction as to carry the pupil upwards and outwards to the upper and outer angle of the eye. *i*, Levator palpebræ superior; *j*, sphenoidal bone (after Gray).

its eyes as it does its legs. When the art of looking and walking has been acquired the seeing and walking movements become, in a sense, involuntary.[1]

The voluntary muscles must be regarded as prime movers; their function being to move the bones of the extremities and other parts in locomotion, and in the handicrafts and arts. They are brought into requisition in pursuing and seizing food; in carrying out the behests of the will as pleasure, duty, and profit suggest. In every case, the voluntary muscles, in a healthy normal body, act directly. Their movements are co-ordinated and controlled to given ends. The nerve supply to the voluntary muscles has to be considered in this connection. It may suffice to say, that the motor nerves, connected with the voluntary muscular movements, form parts of a motor system, and that the muscles, and nerves distributed to them, have much in common, and always work together and in harmony. The muscles and nerves never make war upon each other, and from constant co-operation from birth upwards and from generation to generation habits are formed which result in co-ordinated, and what are loosely regarded as instinctive acts. Voluntary movements, when frequently repeated for long periods, ultimately become involuntary, but it is questionable whether, under any circumstances, involuntary movements can be called "instinctive." I do not think they can.

The fundamental rhythmic structures (chest, heart, stomach, &c.) on which life in the higher animals depends, display spontaneous, independent, centripetal, and centrifugal movements which are typical of all muscular action. The tendency of the voluntary muscles to revert to rhythmic involuntary action is, in every case, well marked; especially where repetition occurs, and where the nervous system, as in insanity, is more or less impaired. A distinction is to be drawn between structures which move spontaneously and independently to given ends, and which cannot be controlled by nerve action, and those which are made to move by volitions or motor impulses conveyed

[1] One of the simplest examples of involuntary muscular movements in striated muscles is that furnished by the external and internal intercostal muscles, which act consentaneously, and in the same direction, whether centripetally or centrifugally. These muscles, when they contract or shorten, elevate the ribs and enlarge the capacity of the chest. The ribs are pulled down and the capacity of the chest diminished by the contraction or shortening of the rectus abdominis muscles; the intercostals meanwhile elongating and acting in harmony. The arrangement of the intercostals is such as to prevent one set elevating the ribs while the other is depressing them, as I explained in 1872–73 ("Physiology of the Circulation in Plants, in the Lower Animals, and in Man;" *Edinburgh Medical Journal*, 1872). The models, consisting of straight-jointed rods and elastic bands, usually employed in the lecture room to demonstrate the action of the external and internal intercostal muscles do not give an accurate representation of them. They represent these muscles as acting separately and at different times, whereas they act conjointly and at the same time.

by motor nerves. This distinction, as stated, is more or less broken down by repetition and by disease of the nervous system.

An animal, whether differentiated or undifferentiated, is to be regarded as a living, sentient, and for the most part conscious mass. It is capable of feeling and moving in all its parts.

Sensation implies motion of a kind, and so does volition. When an animal is touched, a wave of motion caused by molecular vibration travels inwards, that is, into its substance. If the animal moves voluntarily, a similar but opposite wave travels outwards. The animal is expressly formed to realise and take advantage of its surroundings. It receives its information directly, and acts directly and without any roundabout methods—that is, apart from so-called reflex action. In the lowest animal forms sensation and volition are rudimentary, and the one is as simple and direct as the other. A rudimentary consciousness and knowledge of the *ego* can also be predicated. Sensation, volition, and consciousness of a kind must be conceded. The two former involve the latter.

Where all the parts of an animal are homogeneous and simple, the movements are direct—that is, they are, or may be, performed by the mass at once, or after an interval, as in the amœba. The machinery for the so-called reflex or indirect acts does not exist. The direct acts, in such cases, are not the result of irritability, or of extraneous stimulation. They are spontaneous and purposive. The simplest animals are capable of directing their movements to given ends. Living animals feel their way about and know what they are doing. They appropriate and subordinate matter, whether living or dead, to their own uses. This they do in the absence of a visible nervous system as we know it. It is not otherwise with animals higher in the scale, provided with a nervous system consisting only of nerve cells, ganglia, nerve fibres and plexuses; and even in the highest animals, where the nervous system is composed of a brain, spinal cord, and well-defined sensory and motor nerves.

In the medusæ or jelly-fishes the former kind of nervous system obtains. It receives impressions from without by its nerve plexuses, and moves voluntarily from within by means of its nerve cells, ganglia, and nerve fibres. There is no brain, but the movements are so unmistakably voluntary that there can be no suspicion of so-called reflex action in the ordinary sense. The medusæ do not possess irritable integuments, neither are they stimulated into activity by the water in which they are immersed, or by the light and heat to which they are exposed under natural circumstances. A close examination of their movements on various occasions, in the Scottish seas, has fully convinced me that these are spontaneous and voluntary. They are direct and simple. They are, moreover, co-ordinated and rhythmic in character. The medusæ swim in specific directions by quickly closing and more slowly opening their mushroom-shaped mantles or discs and, in a calm sea, make considerable progress. One has only to watch these movements to be convinced that they are intelligent and purposive. The medusæ not only direct their locomotory efforts, but they control all their other movements, such as those connected with feeding, reproduction, &c.[1]

In the highest animals, where a brain, spinal cord, and sense organs are found, all the nervous materials which exist in the medusæ—namely, nerve cells, nerve ganglia, nerve plexuses, and sensory and motor nerves—reappear in a more elaborate form. The simple, direct mode of action is, however, not destroyed by the presence of a brain and spinal cord. The highest animals, as well as the lowest, feel in all their parts, and move in all their parts. This they do by means of their sensory and motor nerves, nerve cells, ganglia, spinal cord, brain, and muscles. The nerve elements are found in a highly differentiated form in the spinal cord and brain; the latter being an expansion and amplification of the former. The entire nervous system in the highest animals is at once sentient and motor throughout. A sensation or sensory impulse travels inwards to the cord and brain from the periphery of the body, and a motor impulse travels outwards from the brain or cord to the muscles. In voluntary movements an impact or sensory impulse travels inwards by molecular wave-vibration to the cord and brain, and a corresponding motor impulse travels outwards from the brain and cord to the muscles to be set in motion.

This can be proved by direct experiment. If a sensory nerve be divided, the portion of skin to which it is distributed becomes insensitive. If, however, the proximal end of the divided sensory nerve be irritated, exquisite pain is experienced; the sensory impression travelling inwards. If, conversely, a motor nerve be divided, irritation of the proximal end of the divided motor nerve produces no movement. If, however, the peripheral end be irritated, movements of the muscles to which the motor nerve is distributed result; the motor impression travelling outwards. In this way the sensory nerves may be described as senso-motor and the motor nerves as moto-sensory. Movement in the substance of nerves, however effected, is a most important factor in nerve action.

The nerve cells and ganglia of the brain and cord do, or may, convert the sensory impulses into motor ones. This is done consciously through the brain or the brain and spinal cord. Sensations, in a healthy animal, are not the result of irritability on the part of the skin or touch corpuscles; neither are they the result of artificial stimu-

[1] I may here state that I am familiar with and have quoted the views of Mr. Romanes on the nervous system of the medusæ. We, however, materially differ as to our interpretations of the phenomena witnessed.

lation. The sensory nerves and skin have their natural or normal objectives. Further, sensations are not necessary to certain forms of voluntary movement. Motor impulses may be the offspring of volition, in which case they are practically commands. They are despatched direct to the voluntary muscles, and the muscles are moved, no sensations or sensory impulses having been transmitted either to the cord or the brain. The brain can act directly, apart from irritability and stimulation.

The movements to and from the cord and brain are incessant during the waking hours, and do not entirely cease during the periods of repose. Most people are busy, thoughtful, and active during the day, and the majority dream during the night.

In making these statements as to the practical uniformity and oneness of the nervous and muscular systems I am not unmindful of the experiments made upon frogs and other animals for the purpose of establishing and extending the scope of so-called reflex action. I have already alluded to some of the well-known frog experiments. If a live frog be decapitated and mustard or other irritant placed on the right thigh, the left foot is used to scrape it off. In like manner the right foot is made to remove the irritant from the left thigh. Similarly, if a probe be inserted in the cloaca of a decapitated frog, both feet are employed in an effort to extract it. The acts of the headless, and therefore brainless, frog are purposive, and indicate a knowledge (however vague) of means to ends. These acts are not satisfactorily explained by habit, or by co-ordinated movements as the result of habit : still less can they be accounted for by what I venture to suggest are erroneously designated as reflex actions. The circumstances are peculiar and exceptional, and are experienced for the first time. They show that the spinal cord with its ganglia and nerve cells and complement of sensory and motor nerves is capable, within limits, and under certain circumstances, of acting independently and, in a sense, voluntarily and consciously. In other words, the ganglia of the cord are to be regarded as brainlets with powers analogous to, and identical with, the powers possessed by the brain proper ; allowance being made for the greater degree of differentiation of the latter. Examples of the regulating power inhering in the nerve cells and ganglia of the spinal cord and brain, apart from what is termed conscious cerebration, are seen in the vegetative structures and appliances of the body.

In animals, especially in the higher ones, there is a considerable number of self-acting, self-regulating structures, such as the lungs, heart, alimentary canal, bladder, uterus, secreting and excreting glands, &c. They are intimately and indissolubly connected with life, and, if any of them fails, death, in the majority of cases, sooner or later supervenes. The structures are involuntary in the sense that they do not require supervision. But, inasmuch as they are living, self-acting structures, and the direct products of an intelligent First Cause, they cannot be regarded as purely mechanical or automatic. They are means to ends, and while their function and scope are in each case determined they have the power of adapting themselves up to a point. If the lungs are diseased, the skin and sudoriferous glands take a more active share in aërating the blood by means of night sweats ; if the skin is not acting, the kidneys come to the rescue : the skin and kidneys act vicariously and reciprocate. If there is constriction and incompetence of the valves of the heart, its walls become thickened, the more effectually to propel the blood. The structures are, up to a point, self-helping and self-repairing. They further exercise what is to be regarded as a selective power, each structure taking from the blood what it requires ; this is especially true of the secreting and excreting glands. Secretions taken from the blood at one part are added to it at another. Effete matters are abstracted from the blood by the skin, lungs, and kidneys, and extruded from the body. In all this there is design, and what are apparently purely mechanical, automatic processes are clearly traceable to an intelligent First Cause. The several structures in the higher animals, whatever their composition, are supplied with nerves which, while they do not necessarily originate, generally regulate their function. The nerves in every instance form an inherent part of the structures, and co-ordinate their movements and functions when required. They also co-ordinate the several systems of the body. If a structure be endowed with fundamental rhythmic movements, so are its nerves. The nerves only act as prime movers when volitions and motor impulses are generated, in which case the cerebro-spinal system and the motor nerves are directly involved. In the vegetative functions of the body the nerves play a subordinate but independent rôle, largely through the sympathetic system. In the cerebro-spinal and sympathetic systems of nerves the essential parts are the nerve cells and ganglia, and to these it is necessary specially to direct attention.

The brain, as is well known, is a mere elaboration and expansion of the spinal cord, the same elements occurring in both. In cases where neither brain nor spinal cord exists, their places are taken by collections of nerve fibres, nerve cells, and ganglia.

The ganglia and nerve cells, in their most simple as well as in their more elaborate and complex combinations, exercise independent directive power, similar to that exercised by the brain as a whole. This is especially true of the ganglia (aggregations of nerve cells), to which the term brainlets may not inappropriately be applied. If this view be adopted, the ganglia or brainlets, with their complements of nerve cells and their sensory and motor nerves,

are to be credited with many of the powers possessed by even the highest and most fully developed nervous systems; those powers diminishing, and becoming dulled, though not wholly destroyed, as we descend in the scale of being. The nervous system, whenever and wherever it occurs, is, when intact, sentient and motor throughout. This view is not negatived by the division in the higher animals of the nerves into sensory and motor respectively. So long as the sensory and motor nerves live, they respond in a rough way to artificial stimulation. Artificial stimulation is, however, a very different thing from natural or healthy normal stimulation. If a divided sensory nerve fails to convey an impression to the ganglia of the spinal cord or the brain, it is because there is a breach of continuity. If a divided motor nerve refuses to set its appropriate muscles in motion at the behest of the brain, it is because there is no longer continuity of structure. An intact nervous system is necessary to normal nerve action. The nerve centres must be unimpaired, and none of the bridges of communication broken down.

The nervous system, as already explained, is conscious, and endowed with a power of knowing and remembering within limits. All animals having a nervous system are capable of profiting by experience and by tuition up to a point. Provision is made for education and progress in the individual and in the race. In this way, and in no other, can the accumulations of predetermined structural and functional peculiarities and habits witnessed in animals, which are referred to heredity, be accounted for.

A consideration of the dawn and development of the nervous system in the lower animals forces me to conclude that the nervous system, even in its most simple form, is the visible expression of a rudimentary conscious intelligence. This seems certain alike from its history and the manner in which it is built up. At first the nervous system consists of a mere aggregation of nerve cells and rudimentary nerve fibres; then ganglia or brainlets and sensory and motor nerve fibres appear; then more or less perfect organs of sense; then a brain and more elaborate organs of sense: then a spinal cord and a brain with at least five well-developed sense organs. As the nervous system gradually reaches its zenith, small but important accretions of consciousness, memory, judgment, and reasoning power are added. It is a mere question of development and elaboration from the lowest to the highest: the difference is not one of kind, but of degree, both as regards structure and function.

In the matter of spontaneity and voluntary movement there can be no doubt that the nervous and muscular systems, where they exist, work harmoniously together to given ends. In some instances (as in thinking) the nervous system performs a separate rôle. It is, however, not to be assumed that a nervous system is necessary either to spontaneity or to voluntary motions in the lowest animals. The movements of the sensitive and insectivorous plants are also, in a certain sense, spontaneous and voluntary. The gradual increase in sensation, consciousness, and the power of knowing, remembering, reasoning, and moving in living things, has practically no halting-place. The Divine will runs through all. All are under surveillance, law, and order. All are conditioned and work to given ends. Their places in time and space are, in every instance, unerringly fixed.

In proof of what is here stated, I propose to give examples of voluntary and other movements, apart from irritability, extraneous stimulation, and so-called reflex action, in the lower and higher animals, directing attention as I proceed to cases of consciousness, memory, reason, and the higher intellectual powers.

MOVEMENT IN RELATION TO INTELLIGENCE: DEVELOPMENT OF INTELLIGENCE

§ 249. Voluntary Movements in the Protozoa and other Lowly Forms.

Any one who has watched and studied the lower animal forms under the microscope must have been struck with the extraordinary exhibitions of what are obviously voluntary movements. These movements are not due to accidental currents, as these rudimentary creatures sometimes avoid and sometimes seek each other for food, for the purposes of reproduction, and apparently also for sport. Mr. Romanes instances a cup-shaped rotifer which he observed had a very active tail armed with strong forceps, with which it seized a considerably larger rotifer. At once the larger rotifer made the most frantic efforts to escape, and jerked itself in every conceivable direction until it effected its purpose. Here we have a deliberate attack, conflict, and escape between two extremely minute microscopic objects in which no nerves or muscles can be detected. The encounter was, to all appearance, one of conscious, intelligent, determined action, and extended over several minutes.

Mr. H. J. Carter [1] remarks that "even Æthalium will confine itself to the water of the watch-glass in which it may be placed when away from sawdust and chips of wood among which it has been living; but if the watch-glass be placed upon the sawdust, it will very soon make its way over the side of the watch-glass and get to it." Here the myxomomycete distinguishes between the water and the sawdust through the watch-glass. It was content to remain

[1] "Annals of Natural History," by H. J. Carter, F.R.S., vol. xii. 1863, pp. 45, 46.

in the water in the absence of sawdust, but immediately left it when sawdust was within reach. The action was deliberate, and bespoke judgment and intelligence of a kind.

Mr. Carter adduces two other remarkable examples of intelligence in low microscopic forms. He says: "On one occasion I saw an *Actinophrys* station itself close to a ripe spore-cell of *Pythium*, which was situated upon a filament of *Spirogyra crassa;* and as the young ciliated monadic germs issued forth, one after another, from the dehiscent spore-cell, the *Actinophrys* remained by it and caught every one of them, even to the last, when it retired to another part of the field, as if instinctively conscious that there was nothing more to be got at the old place."

"But by far the greatest feat of this kind that ever presented itself to me was the catching of a young acineta by an old sluggish amœba, as the former left its parent: and this took place as follows:—

"In the evening of the 2nd of June, 1858, in Bombay, while looking through a microscope at some *Euglenæ*, &c., which had been placed aside for examination in a watch-glass, my eye fell upon a stalked and triangular acineta (*A. mystacina?*), around which an amœba was creeping and lingering, as they do when they are in quest of food. But knowing the antipathy that the amœba, like almost every other infusorian, has to the tentacles of the acineta, I concluded that the amœba was not encouraging an appetite for its whiskered companion, when I was surprised to find that it crept up the stem of the acineta, and wound itself round its body. This mark of affection, too much like that frequently evinced at the other end of the scale, even where there is a mind for its control, did not long remain without interpretation. There was a young acineta, tender, and without poisonous tentacles (for they are not developed at birth), just ready to make its exit from the parent, an exit which takes place so quickly, and is followed by such rapid bounding movements of the non-ciliated acineta, that who would venture to say, *à priori*, that a dull, heavy, sluggish amœba could catch such an agile little thing? But the amœbæ are as unerring and unrelaxing in their grasp as they are unrelenting in their cruel inceptions of the living and the dead, when they serve them for nutrition: and thus the amœba, placing itself round the ovarian aperture of the acineta, received the young one, nurse-like, in its fatal lap, incepted it, descended from the parent, and crept off. Being unable to conceive at the time that this was such an act of atrocity on the part of the amœba as the sequel disclosed, and thinking that the young acineta might yet escape, or pass into some other form in the body of its host, I watched the amœba for some time afterwards, until the tale ended by the young acineta becoming divided into two parts, and thus in their respective digestive spaces ultimately becoming broken down and digested." The amœba, as is well known, is one of the simplest of animals. It certainly reveals no trace of nerve or muscle, or any of those structures which we associate with intelligence and voluntary movement.

§ 250. The Cœlenterata.

Dr. Eimer attributes voluntary action to the medusæ (jelly-fishes), and draws a sharp distinction between what he considers their "voluntary" and "involuntary" movements. In the medusæ we have the first beginnings of a nervous system. It consists of nerve cells, ganglia, and nerve fibres and plexuses, but no brain of any kind can be made out.

Mr. McGrady supplies some interesting information regarding a medusa which carries its larvæ on the inner side of its bell-shaped body. "The manubrium, or mobile digestive cavity of the animal, depends, as in the other medusæ, from the summit of the concave surface of the bell, like a clapper or tongue. This depending organ moved first to one side and then to the other side of the bell, in order to give suck to the larvæ on the sides of the bell—the larvæ dipping their long noses into the nutrient fluids which that organ of the parent's body contained." Here we have an example of the parent feeding its offspring at intervals in an intelligent manner. The larvæ did not act as irritants to the manubrium which was jerked towards them. The nutrient fluids were prepared and carried to the larvæ in succession.

Certain medusæ—*Sarsia*, for example—seek the light and follow it, impelled, there is reason to believe, by its revealing small crustacea on which they feed.

§ 251. The Annelida.

The earthworms, according to Mr. Darwin, draw down leaves and other materials into their burrows in such a way as to avoid friction and reduce resistance. They seize the leaves where the pull is most effective, so as to conserve energy and produce a maximum result. Here there is intelligence of a kind. It is not a case of purposeless so-called reflex action brought about by irritation. The nervous system of the earthworm is sufficiently advanced to account for its mechanical skill.

Land leeches, as Sir E. Tennent explains, display singular powers when in quest of prey. The following is his account:[1] "In moving, the land leeches have the power of planting one extremity on the earth and raising the other perpendicularly to watch for their victim. Such is their vigilance and instinct, that on the approach of a passer-by to a spot which they infest, they may be seen amongst the grass and fallen leaves on the edge of a native path, poised erect, and preparing for their attack on man and horse. On descrying their prey they advance rapidly by semicircular strides, fixing one end firmly and arching the other forwards, till by successive advances they can lay hold of the traveller's foot, when they disengage themselves from the ground and ascend his dress in search of an aperture to enter. In these encounters the individuals in the rear of a party of travellers in the jungle invariably fare worst, as the leeches, once warned of their approach, congregate with singular celerity."

The leeches, according to this account, act individually and in concert and to a given end. They display prescience of a kind. Their movements and general conduct certainly cannot be explained by mere so-called reflex action, irritation, and stimulation. The leeches are provided with a well-defined nervous, muscular, and circulatory system.

§ 252. The Larvæ of Insects.

The larvæ of insects in certain cases display considerable intelligence, this, not unfrequently, being greater in the larvæ than in the imago state, although the latter is the more advanced stage of existence. Development does not necessarily always mean mental or psychical development.

Messrs. Kirby and Spence[2] observe "that the common cabbage caterpillar, when making a web to support its dependent pupa under stone or wooden surfaces, covers the space to be occupied as a base with web, but that if the surface to be utilised be a muslin one, the basal web is dispensed with. Similarly, a caterpillar described by M. Bonnet, confined in a box, and cut off from the bark with which it usually makes its cocoon, employed instead small pieces of paper with which it was supplied. These it tied together with silk. In the case of the cocoons of the moth (*Noctua verbasci*), composed of grains of earth and silk, which were opened and injured, the injured parts were not always repaired in the same way. Some employed earth and silk, others wove a silken veil to patch up the breach.

"The caterpillars in these cases showed adaptive skill, and employed different means in arriving at the same end.

"The larva of the ichneumon, while feeding upon its caterpillar host, spares the walls of the intestines until it is time for it to escape, when, the life of the caterpillar being no longer necessary to its development, it perforates these walls.

"The larvæ *Thecla isocrates* live in a group of seven or eight in the fruit of the pomegranate. In consequence of their excavations within the fruit, the latter is apt to fall; and to prevent its doing so the larvæ throw out a thread of attachment wherewith to secure the fruit to the branch, so that, if the stalk withers, this thread serves to suspend the fruit.

"The caterpillar of the Bombyx moth, which is a native of France, exhibits very wonderful instincts. [I say nothing, at present, as to what instinct really is.] The larva is gregarious in its habits, each society (family) consisting of perhaps 600 or 800 individuals. When young they have no fixed habitation, but encamp sometimes in one place, and sometimes in another, under the shelter of their web; but when they have attained two-thirds of their growth, they weave for themselves a common tent. About sunset the regiment leaves its quarters. . . . At their head is a chief, by whose movements their procession is regulated. When he stops all stop, and proceed when he proceeds; three or four of his immediate followers succeed in the same line, the head of the second touching the tail of the first; then comes an equal series of pairs, next of three, and so on, as far as fifteen or twenty. The whole procession moves regularly on with an even pace, each file treading in the steps of those that precede it. If the leader, arriving at a particular point, pursues a different direction, all march to that point before they turn."

The larva of the *Tinea* moth, according to Réaumur,[3] feeds upon the leaves of the elm, which provides it both with food and clothing. "To do this it only eats the parenchyma of the leaf, preserving the upper and under epidermal membranes, between which it then insinuates itself as it progressively devours the parenchyma." "It takes care to avoid separating the membranes at the extreme edge, lines them with silk, makes them cylindrical in shape, and thus provides itself with a close-fitting coat. The side opposite the extreme edge is sewed up and the ends of the coat cut off. Its coat being open at both ends, it is free to feed and discharge its excreta."

On one occasion Réaumur removed the edge of a newly made coat. The larva sewed up the rent, but (and this is remarkable) "the scissors having cut off one of the projections intended to enter into the construction of the

[1] "Natural History of Ceylon," p. 481. [2] Kirby and Spence, "Entomology," Letters xi. and xvi. [3] "L'Histoire des Insectes."

triangular end of the case, it entirely changed the original plan, and made that end the head which had been first designed for the tail."

This larva not only displays great constructive skill, but shows a power of changing its plan and adapting its design to altered and unusual circumstances.

Réaumur states that the larvæ of *Hemerobius chrysops* pursue aphides, kill them, and appropriate their skins as coverings, and W. MacLachlan avers that the caddis-worms adjust the specific gravity of their tubes to the water they inhabit, adding or taking off weight as required.

The ant-lion, the larval condition of the common *Myrmeleon* (*M. formicarium*) is an adroit strategist and hunter. He adopts tactics greatly resembling those resorted to by the fishing frog (*Lophius piscatorius*).

Thompson in his "Passions of Animals" (p. 258) thus describes this cunning and audacious grub : "He forms, with astonishing labour and perseverance, a pit in the shape of a funnel in a dry, sandy soil, under some old wall or other spot protected from the wind. His pit being finished, he buries himself among the sand at the bottom, leaving only his horns visible, and thus waits patiently for his prey. When an ant or any other small insect happens to walk on the edge of the hollow, it forces down some of the particles of sand, which gives the ant-lion notice of its presence. He immediately throws up the sand which covers his head to overwhelm the ant, and with its returning force brings it to the bottom. This he continues to do till the insect is overcome and falls between his horns. Every endeavour to escape, when once the incautious ant has stepped within the verge of the pit, is vain, for in all its attempts to climb the side the deceptive sand slips from under its feet, and every struggle precipitates it still lower. When within reach its enemy plunges the points of its jaws into its body, and having sucked out all its juices, throws out the empty skin to some distance."

§ 253. The Mollusca.

It has been shown by Dicquemare [1] "that oysters dredged from depths never uncovered at low tide open their shells, part with the water they contain, and die within a comparatively short period ; whereas the same oysters, if placed in reservoirs and occasionally uncovered and left dry, learn to keep their shells closed, and so live for considerable periods when wholly deprived of water. This fact has been turned to account in the cultivation of oysters and oyster transit in France. The oysters are deprived of water at intervals, and for increasingly long periods, until they are educated to keep their shells closed a sufficiently long time to admit of their being sent from the coast to Paris alive and healthy."

This is a clear case of education and training, and, if so, the oyster must be accredited with the power of knowing and remembering, and being, within limits, conscious.

Bingley [2] states "that such is the aversion of the razor-fishes for salt that if it be sprinkled over their burrows in the sand they immediately come to the surface. If, however, by any chance they are caught and liberated, no amount of salt will induce them to come to the surface a second time. This indicates intelligence and memory, and the power of grasping the situation. It is scarcely necessary to observe that the oysters and razor-fishes are provided with nervous systems."

Some remarkable facts are recorded of snails. Mr. W. White "fixed a land-snail mouth uppermost in a chink of rock ; in a short time the snail protruded itself to its utmost length, and, attaching its foot vertically above, tried to pull the shell out in a straight line. Not succeeding, it rested for a few minutes and then stretched out its body on the right side and pulled its utmost, but failed. Resting again, it protruded its foot on the left side, pulled with all its force, and freed the shell. This exertion of force in three directions, which seems so geometrically suitable, must have been intentional." [3]

Mr. Darwin in his "Descent of Man" [4] quotes the following from Mr. Lonsdale as showing intelligence and attachment in snails : "Mr. Lonsdale informs me that he placed a pair of land-snails (*Helix pomatia*), one of which was weakly, into a small and ill-provided garden. After a short time the strong and healthy individual disappeared, and was traced by its track of slime over a wall into an adjoining well-stocked garden. Mr. Lonsdale concluded that it had deserted its sickly mate ; but after an absence of twenty-four hours it returned, and apparently communicated the result of its successful exploration, for both then started along the same track, and disappeared over the wall."

That the limpet possesses memory and considerable powers of intelligence will appear from the following facts recorded by Mr. J. Clarke Hawkshaw in the *Journal of the Linnæan Society :* "The holes in the chalk in which the limpets are often to be found are, I believe, excavated in a great measure by rasping from the lingual teeth,

[1] *Journal de Physique*, vol. xxviii. p. 244.
[2] Bingley, "Animal Biography," vol. iii. p. 449.
[3] "A Londoner's Walk in Edinburgh," 1856, p. 155.
[4] "Descent of Man," pp. 262, 263.

though I doubt whether the object is to form a cavity to shelter in, though the cavities, when formed, may be of use for that purpose. It must be of the greatest importance to a limpet that, in order that it may insure a firm adherence to the rock, its shell should fit the rock accurately; when the shell does fit the rock accurately, a small amount of muscular contraction of the animal would cause the shell to adhere so firmly to a smooth surface as to be practically immovable without fracture. As the shells cannot be adapted daily to different forms of surface, the limpets generally return to the same place of attachment. I am sure this is the case with many; for I found shells perfectly adjusted to the uneven surfaces of flints, the growth of the shells being in some parts distorted and indented to suit inequalities in the surface of the flints. . . .

"I noticed signs that limpets prefer a hard, smooth surface to a pit in the chalk. On one surface of a large block, over all sides of which limpets were regularly and plentifully distributed, there were two flat fragments of a fossil shell about three inches by four inches, each imbedded in the chalk. The chalk all round these fragments was free from limpets; but on the smooth surface of the pieces of shell they were packed as closely as they could be. I noticed another case, which almost amounts, to my mind, to a proof that they prefer a smooth surface to a hole. A limpet had formed a clearing on one of the seaweed-covered blocks before referred to. In the midst of this clearing was a pedestal of flint rather more than one inch in diameter, standing up above the surface of the chalk; it projected so much that a tap from my hammer broke it off. On the top of the smooth fractured surface of this flint the occupant of the clearing had taken up its abode. The shell was closely adapted to the uneven surface, which it would only fit in one position. The cleared surface was in a hollow with several small natural cavities, where the limpet could have found a pit ready made to shelter in; yet it preferred, after each excursion, to climb up to the top of the flint, the most exposed point in all its domain."

The *Cephalopoda*, or cuttle-fishes, possess an astonishing degree of intelligence. This sub-kingdom of the molluscs are at once old and new world forms, and their persistence in time and space invests them with an unusual degree of interest. According to Schneider,[1] who studied them for protracted periods at the Zoological Station, Naples, they present "unmistakable evidence of consciousness and intelligence." He asserts that they even knew the keeper who fed them.

Hollmann,[2] a trustworthy observer, gives an account of an encounter between an octopus and a lobster which shows determination and consummate generalship on the part of the former. The lobster, which was worsted in the struggle, was removed for safety to an adjoining tank. Thither the cuttle-fish followed it in spite of all obstacles. In order to renew the struggle the cuttle-fish had to clamber up the vertical partition which separated it from its victim. As this partition projected above the water in the tanks it had to leave the water before it could descend on the other side of the partition. All this it did, showing a knowledge of ways and means truly remarkable. It did not desist until it destroyed its adversary. Another instance is recorded where a comparatively small octopus attacked a large lobster. The large lobster was getting the best of the encounter when the octopus made a strategic backward movement to a favourite corner, where it fixed itself by means of its suckers. This done, it deliberately tore the lobster limb from limb by its powerful, all-embracing arms. These encounters display a knowledge of means to ends, and a deliberate forethought and judgment, which entitle them to be regarded as conscious, reasoning creatures. Their actions were in no sense what are called reflex, mechanical, or due to extraneous stimulation. On the contrary, they were spontaneous and voluntary. They were also purposive, and executed with a full knowledge of the object to be attained.

The cuttle-fishes are credited with an abstract idea of water, and attempt to return to it when removed from it and when they do not see it.

Of course the nervous system in the cephalopoda is fairly well advanced, consisting as it does of a brain, ganglionic centres of various kinds, and sensory and motor nerves. Its sense organs, especially its eyes, attain a considerable degree of differentiation.

§ 254. The Spiders.

The spiders are found in all quarters of the globe, and hold a distinguished place for intelligence and courage. They are also emotional, and display great affection for their offspring.

"Bonnet threw a spider with her bag of eggs into the pit of an ant-lion. The latter seized the eggs and tore them away from the spider; but although Bonnet forced her out of the pit, she returned, and chose to be dragged in and buried alive rather than leave her charge."[3]

The loves of spiders are phenomenal, and not unattended with danger to the male, which is very small as

[1] "Thieresche Wille," p. 78.
[2] "Leben der Cephalopoden," p. 21.
[3] Romanes, "Animal Intelligence," p. 205.

compared with the female. If the male proves maladroit he sometimes forfeits his life to his huge spouse, who destroys and eats him. Spiders are proverbially voracious. They present a strange mixture of ferocity and tenderness. They are fond of music, especially if it be soft and low (Romanes, p. 206). "Professor C. Reclain, during a concert at Leipsic, saw a spider descend from one of the chandeliers while a violin solo was being played; but as soon as the orchestra began to sound it quickly ran back again. Similar observations have been published by Rabigot, Simonius, Von Hartmann, and others."

The predilection of spiders for music has probably some connection with their mode of feeding; flies and buzzing insects forming the staple thereof. However this may be, there can be no doubt that spiders are exceedingly sensitive to every kind of vibration, whether natural or artificial.

Mr. C. V. Boys made some interesting tuning-fork experiments with garden spiders as follows:[1] "Last autumn, while watching some spiders spinning their beautiful geometrical webs, it occurred to me to try what effect a tuning-fork would have upon them. On sounding an A fork, and lightly touching with it any leaf or other support of the web, or any portion of the web itself, I found that the spider, if at the centre of the web, rapidly slues round so as to face the direction of the fork, feeling with its fore-feet along which radial thread the vibration travels. Having become satisfied on this point, it next darts along that thread till it reaches either the fork itself or a junction of two or more threads, the right one of which it instantly determines as before. If the fork is not removed when the spider has arrived it seems to have the same charm as any fly; for the spider seizes it, embraces it, and runs about on the legs of the fork as often as it is made to sound, never seeming to learn by experience that other things may buzz besides its natural food.

"If the spider is not at the centre of the web at the time that the fork is applied it cannot tell which way to go until it has been to the centre to ascertain which radial thread is vibrating, unless of course it should happen to be on that particular thread, or on a stretched supporting thread in contact with the fork.

"If, when a spider has been enticed to the edge of the web the fork is withdrawn, and then gradually brought near, the spider is aware of its presence and of its direction, and reaches out as far as possible in the direction of the fork; but if a sounding fork is gradually brought near a spider that has not been disturbed, but which is waiting as usual in the middle of the web, then, instead of reaching out towards the fork, the spider instantly drops —at the end of a thread, of course. If under these conditions the fork is made to touch any part of the web, the spider is aware of the fact, and climbs the thread and reaches the fork with marvellous rapidity. The spider never leaves the centre of the web without a thread along which to travel back. If after enticing a spider out we cut this thread with a pair of scissors, the spider seems unable to get back without doing considerable damage to the web, generally gumming together the sticky parallel threads in groups of three and four. . . .

"The few house-spiders that I have found do not seem to appreciate the tuning-fork, but retreat into their hiding-places as when frightened; yet the supposed fondness of spiders for music must surely have some connection with these observations; and when they come out to listen, is it not that they cannot tell which way to proceed?"

The most outstanding feature connected with spiders is their power of spinning webs for the capture of prey. This is a unique endowment in the animal kingdom, and deserves a more than passing word. Other animals, such as caterpillars, silkworms, &c., can and do spin threads for letting themselves down from heights, for covering themselves, and other purposes, but it is reserved for the spiders deliberately and presciently to spin webs for ensnaring prey. To this end they are provided with a special spinning apparatus. They are physically endowed with the wherewithal to produce threads of extreme tenuity and in great numbers. In the spider, as in all other animals, structure precedes function. The threads are not chance products, and they are voluntarily produced, apart from external stimulation. It has been ascertained that the young spiders do not produce quite such perfect webs as the adults, so that the animal learns from experience. The web of an adult spider is one of the wonders of nature, and is on a par with the comb of the honey bee as regards design and the extraordinary delicacy and excellence of the workmanship. It is, moreover, mathematically perfect if regard be had to symmetry, strength, and the amount of materials employed. The webs are of various kinds. "Thus we have, in different species, wide open networks spread between the branches of bushes, &c., closely woven textures in the corners of buildings, earth tubes lined with silk, the strong muslin-like snare of the Mygale, which, as first noticed by Madame Merian, and since confirmed by Bates, is able to retain a struggling humming-bird while this most beautiful animal in creation is being devoured by the most repulsive: and many other varieties might be mentioned."[2]

The following is the account given by Mr. Romanes[3] of the formation of spiders' webs: "Without going into the anatomy of the subject I may observe that a spider's 'thread' is a composite structure made up of a number of finer threads, which leave their respective spinneret-holes in an almost fluid condition, and immediately harden by exposure to the air.

[1] Op. cit., p. 206. [2] Op. cit., p. 208. [3] Op. cit., p. 209.

"The so-called 'geometric spider' constructs her web by first laying down the radiating and unadhesive rays, and then, beginning from the centre, spins a spiral line of unadhesive web, like that of the rays which it intersects. This line, in being woven through the radii in a spiral from centre to circumference, serves as a scaffolding for the spider to walk over, and also keeps the rays properly stretched. She next spins another spiral line, but this time from the circumference to near the centre, and formed of web, covered with a viscid secretion to retain prey. Lastly, she constructs her lair to hide and watch her prey, at some distance from the web but connected with it by means of a line of communication or telegraph, the vibrations of which inform her of the struggling of an insect in the net.

"According to Mr. Thompson,[1] the web of the garden spider—the most ingenious and perfect contrivance that can be imagined—is usually fixed in a perpendicular or somewhat oblique direction in an opening between the leaves of some plant or shrub; and as it is obvious that round its whole extent lines will be required to which those ends of radii that are farthest from the centre can be attached, the construction of those exterior lines is the spider's first operation. It seems careless about the shape of the area they are to enclose, well aware that it can as readily inscribe a circle in a triangle as in a square; and in this respect it is guided by the distance or proximity of the points to which it can attach them. It spares no pains, however, to strengthen and keep them in a proper degree of tension. With the former view it composes each line of five or six or even of more threads glued together; and with the latter it fixes to them from different points a numerous and intricate apparatus of smaller threads; and having thus completed the foundation of its snare, it proceeds to fill up the outline. Attaching a thread to one of the main lines, it walks along it, guiding it with one of its hind legs, that it may not touch in any part and be prematurely glued, and crosses over to the opposite side, where, by applying its spinners, it firmly fixes it. To the middle of this diagonal thread, which is to form the centre of its net, it fixes a second, which in like manner it conveys and fastens to another part of the lines including the area. The work now proceeds rapidly. During the preliminary operations it sometimes rests, as though its plan required meditation; but no sooner are the marginal lines of the net firmly stretched, and two or three radii spun from its centre, than it continues its labour so quickly and unremittingly that the eye can scarcely follow its progress. The radii, to the number of about twenty, giving the net the appearance of a wheel, are speedily finished. It then proceeds to the centre, quickly turns itself round, pulls each thread with its feet to ascertain its strength, breaking any one that seems defective, and replacing it by another. Next it glues, immediately round the centre, five or six small concentric circles, distant about half a line from each other, and then four or five larger ones, each separated by the space of half an inch or more. These last serve as a sort of temporary scaffolding to walk over, and to keep the radii properly stretched while it glues to them the concentric circles that are to remain, which it now proceeds to construct. Placing itself at the circumference, and fastening its thread to the end of one of the radii, it walks up that one, towards the centre, to such a distance as to draw the thread from its body of a sufficient length to meet the next. Then stepping across and conducting the thread with one of its hind legs, it glues it with its spinners to the point in the adjoining radius to which it is to be fixed. This process it repeats until it has filled up nearly the whole space from the circumference to the centre with concentric circles, distant from each other about two lines. It always, however, leaves a vacant interval around the smallest first spun circles that are nearest to the centre, and bites away the small cotton-like tuft that united all the radii, which being held now together by the circular threads have thus probably their elasticity increased; and in the circular opening, resulting from this procedure, it takes its station and watches for its prey, or occasionally retires to a little apartment formed under some leaf, which it also uses as a slaughter-house.

"According to Büchner, the long main threads, with the help of which the spider begins and attaches its web, are always the thickest and strongest, while the others, forming the web itself, are considerably weaker. Injuries to the web at any spot the spider very quickly repairs, but without keeping to the original plan, and without taking more trouble than is absolutely necessary. Most spider's webs, therefore, if closely looked into, are found to be somewhat irregular. When a storm threatens, the spider, which is very economical with its valuable spinning material, spins no web, for it knows that the storm will tear it in pieces and waste its pains, and it also does not mend a web which has been torn. If it is seen spinning or mending, on the other hand, fine weather may be generally reckoned on. . . . The emerged young at first spin a very irregular web, and only gradually learn to make a larger and finer one, so that here, as everywhere else, practice and experience play a great part. . . . The position must also offer favourable opposite points for the attachment of the web itself. People have often puzzled their brains, wondering how spiders, without being able to fly, had managed first to stretch their web through the air between two opposite points. But the little creature succeeds in accomplishing this difficult task in the most various and ingenious ways. It either, when the distance is not too great, throws a moist viscid pellet, joined to a thread,

[1] Thompson's "Passions of Animals," p. 145.

which will stick where it touches; or hangs itself by a thread in the air and lets itself be driven by the wind to the spot; or crawls there, letting out a thread as it goes, and then pulls it taut when arrived at the desired place; or floats a number of threads in the air and waits till the wind has thrown them here or there. The main or radial threads which fasten the web possess such a high degree of elasticity that they tighten themselves between two distant points to which the spider has crawled, without it being necessary for the latter to pull them towards itself. When the little artist has once got a single thread at its disposition, it strengthens this until it is sufficiently strong for it to run backwards and forwards thereupon, and to spin therefrom the web." [1]

Not only do spiders display extraordinary ingenuity in constructing their webs; they also exhibit great resource in repairing them when damaged, in strengthening weak parts, and in ballasting them when driven about by the wind. When the webs are too slack and swing about, the spiders attach little stones and other heavy objects to their under surfaces.

"Gleditsch saw a spider so circumstanced let itself down to the ground by means of a thread, seize a small stone, remount, and fasten the stone to the lower part of its web, at a height sufficient to enable animals and men to walk beneath it. A similar observation was made by Professor E. H. Weber, the famous anatomist and physiologist, and was published many years ago in Müller's Journal. A spider had stretched its web between two posts standing opposite each other, and had fastened it to a plant below for the third point. But as the attachment below was often broken by the garden work, by passers-by, and in other ways, the little animal extricated itself from the difficulty by spinning its web round a little stone, and fastened this to the lower part of its web, swinging freely, and so to draw the web down by its weight instead of fastening it in this direction by a connecting thread." [2]

The powers possessed by spiders of mending and strengthening their nets is scarcely less remarkable than their power of original fabrication: spiders mend their nets as dexterously as fishermen do theirs or good housewives darn stockings. I have seen a large spider handle a bluebottle fly, which was caught by it damaging its net, in the most intelligent and business-like manner. The spider darted out from its hiding-place, and apparently took in the situation at a glance. The bluebottle was not only destroying the net, but its strength and vigour were such that there was a danger of its escaping. There was no time for deliberation, but the spider was quite equal to the occasion. It seized the net in the vicinity of the insect and literally enveloped it in it. It then availed itself of some of the main threads of the net, which it employed as guy ropes in steadying and supporting the threatened structure. So swathed, the fly was left to struggle and die.

The manner in which spiders convey the quarry to their larder or storehouse is interesting. This, if not too large, is carried off bodily. If large it is pulled or dragged with or without the aid of specially prepared threads.

Mr. L. A. Morgan thus describes the process: [3] "The spider first went two or three times backwards and forwards between the head of the insect and the main strand of the web. After this he went about cutting all the threads around the insect till the latter hung by the head strands alone. The spider then fixed a thread to the tail end, and by this dragged the carcass as far on its way to the larder as the head strands would permit. As soon as these were taut, he made the tail rope fast, went back to the head rope and cut it; then he attached himself to the head and pulled the body towards the larder, until the tail rope was taut. In this way, by alternately cutting the head and tail ropes and dragging the insect bit by bit, he conveyed it safely to the larder."

Among the land spiders reference should be made to the so-called trap-door spiders. These occur in large numbers on the Riviera, where I have had opportunities of studying them. They are distinguished by their habit of making single or branching burrows, which they cover with one or two jointed lids. These burrows and lids are constructed for safety and comfort during the cold season. The burrow or nest "consists of a tube excavated in the earth to the depth of half a foot or more. In all save one species the tube is unbranched; it is always lined with silk, which is continuous with the lining of the trap-door or doors, of which it forms the hinge. In the species which constructs a branching tube, the branch is always single, more or less straight, takes origin at a point situated a few inches from the orifice of the main tube, is directed upwards at an acute angle with that tube, and terminates blindly just below the surface of the soil. At its point of junction with or departure from the main tube it is provided with a trap-door resembling that which closes the orifice of the main tube, and of such a size and arrangement that when closed against the opening of the branch tube it just fills that opening; while when turned outwards, so as to uncork this opening, it just fills the diameter of the main tube: the latter, therefore, is in this species provided with two trap-doors, one at the surface of the soil, and the other at the fork of the branched tube.

"Each species of trap-door spider is very constant in building a particular kind of trap-door; but among the different species there are four several kinds of trap-doors to be distinguished. 1st. The single-door cork nest,

[1] Büchner, "Geistesleben der Thiere," p. 316 *et seq.*
[2] Romanes, "Animal Intelligence," pp. 220, 221.
[3] *Nature*, January 22, 1880.

wherein the trap-door is a thick structure, and fits into the tube like a cork into a bottle. 2nd. The single-door wafer nest, wherein the trap-door is as thin as a piece of paper. 3rd. The double-door unbranched nest, wherein there is a second trap-door situated at a few inches below the first one. And 4th. The double-door branched nest already described. In all cases the trap-doors open outwards, and when the nest is placed, as it usually is, on a sloping bank, the trap-door opens upwards; hence there is no fear of its gaping, for gravity is on the side of holding it shut.

"The object of the trap-door is to conceal the nest, and for this purpose it is always made so closely to resemble the general surface of the ground on which it occurs, that even a practised eye finds it difficult to detect the structure when closed. In order to make the resemblance to the surrounding objects as perfect as possible, the spider either constructs the surface of its door of a portion of leaf, or weaves moss, grass, &c., into the texture. . . .

"If an enemy should detect the trap-door and endeavour to open it, the spider frequently seizes hold of its internal surface, and, applying her legs to the walls of the tube, forcibly holds the trap-door shut. In the double trap-door species it is surmised that the second trap-door serves as an inner barrier of defence, behind which the spider retires when obliged to abandon the first one. In the branched tube species (which, so far as at present known, only occurs in the south of Europe) it is surmised that the spider, when it finds that an enemy is about to gain entrance at the first trap-door, runs into the branch tube and draws up behind it the second trap-door. The surface of this trap-door, being overlaid with silk like the walls of the tube, is then invisible; so that the enemy no doubt passes down the main tube to find it empty, without observing the lateral branch in which the spider is concealed behind the closed door."

Referring to young trap-door spiders Moggridge writes: "I cannot help thinking that these very small nests, built as they are by minute spiders probably not very long hatched from the egg, must rank among the most marvellous structures of this kind with which we are acquainted. That so young and weak a creature should be able to excavate a tube in the earth many times its own length, and know how to make a perfect miniature of the nest of its parents, seems to be a fact which has scarcely a parallel in nature."

Romanes states that "*Lycosa narbonensis*, a spider of Southern France, much resembling the Apuleian tarantula, and belonging to the family of wolf spiders, makes cylindrical holes in the earth, about one inch wide and three or four inches deep, in a perpendicular direction; when they have attained this depth they run further horizontally, and end in a three-cornered room, from one to two inches broad, the floor of which is covered with the remnants of dead insects. The whole nest is lined within with a thick silken material, and has at its opening —closed by no door—an above-ground, chimney-shaped extension, made of leaves, needles, moss, wood, &c., woven together with spider threads. These chimneys show various differences in their manner of building, and are intended chiefly, according to Moggridge, to prevent the sand blown about by the violent sea-winds from penetrating into the nests. During winter the opening is wholly and continuously woven over, and it is very well possible, or probable, that the process of reopening such a warm covering in the spring, after this opening was three-quarters completed, and was large enough to let the spider pass out, may have long ago awaked in the brain of some species of spider the idea of making a permanent and movable door. But from this to the practical construction of so perfect a door as we have learned to know, and even to the building of the exceedingly complicated nest of the *N. Manderstjernæ*, through all the gradations which we already know, and which doubtless exist in far greater number, is no great or impossible step." [1]

The water spider (*Argyroneta aquatica*) if possible displays more intelligence than its gifted relatives in constructing its nest. This is built, as a rule, under the surface of still water, on the principle of the diving-bell. The nest is oval in shape, lined with web, and moored by threads to water plants. It is open below, and filled with air for respiratory purposes. The manner in which the spider supplies her nest with air is remarkably ingenious. "The air needful for respiration the spider carries from the surface of the water. To do this she swims upon her back in order to entangle an air-bubble upon the hairy surface of her abdomen. With this bubble she descends, 'like a globe of quicksilver,' to the opening of her nest, where she liberates it and returns for more." [2] In her tiny diving-bell the spider watches for her prey. According to Kirby she also spends the winter there after having closed the opening.

The hunting spider (*Dolomedes fimbriatus*) does not construct a web or nest, and hunts its victims like animals of prey on land and even on water. It can walk with facility on the water, but as it requires to rest occasionally it constructs rafts by rolling dry leaves together and binding them with threads. On this tiny raft it floats about securely, and if by any chance an ill-starred water insect comes to the surface to breathe it is instantly seized and carried back triumphantly to the raft, where it is devoured at leisure.

[1] Romanes, "Animal Intelligence," pp. 213, 214, 215, and 217.

[2] Op. cit., p. 212.

The vagrant or wolf spider (*Salticus scenicus*) literally stalks and pounces upon its victim, fixing a line of web along its path to prevent its falling in the event of over-reaching or missing its prey.

That spiders are endowed with intelligence cannot seriously be doubted. There is a large amount of concurrent testimony to the effect that spiders can be tamed, and that they can distinguish between persons.

Prisoners have frequently made pets of spiders, and individuals who feed spiders at regular intervals are eagerly welcomed by them.

Dr. Moschkau fed a spider several times a day with flies held in a forceps. At first the spider took the fly timidly and hurriedly. Latterly it seized it boldly and with confidence. On one occasion the doctor in sport took away and returned the fly which the spider had seized. The spider was annoyed and sulked. On another occasion he completely removed the fly. This broke up the friendship. On the following day the spider refused to accept a fly from him, and on the third day it disappeared.

Jesse[1] gives an instance of a spider adapting its actions to uncongenial surroundings. He placed a spider with her eggs on a marble mantelpiece under a glass bell jar. The cold of the mantelpiece evidently discomfited the spider. She therefore wrapped her eggs in web and lifted them above the mantelpiece by means of threads extending between different parts of the glass and a piece of grass contained in it.

Mr. Belt gives an instance of the sagacity displayed by South American spiders in escaping from the dreaded hosts of the Eciton ants. He says : "Many of the spiders would escape by hanging suspended by a thread of silk from the branches, safe from the foes that swarmed both above and below.

"I noticed that spiders generally were most intelligent in escaping, and did not, like the cockroaches and other insects, take shelter in the first hiding-place they found, only to be driven out again, or perhaps caught by the advancing army of ants. I have often seen large spiders making off many yards in advance, and apparently determined to put a good distance between themselves and the foe."[2]

Before leaving the spiders it may be as well to say a word regarding the scorpions. These fierce and intractable creatures do not spin webs or build nests, and are referred to here in connection with their alleged tendency to self-destruction if surrounded by fire. This tendency, long considered apocryphal, has of late been confirmed. Mr. W. G. Bidie experimented on a large black common scorpion of Southern India with the following results. He placed the scorpion in a glazed entomological case in the rays of the hot sun. He then took a botanical lens and focussed the rays of the sun on its back. "The moment this was done it began to run hurriedly about the case, hissing and spitting in a very fierce way. This experiment was repeated some four or five times with like results, but on trying it once again, the scorpion turned up its tail and plunged the sting, quick as lightning, into its own back. The infliction of the wound was followed by a sudden escape of fluid, and a friend standing by me called out, 'See, it has stung itself : it is dead :' and sure enough in less than half a minute life was quite extinct."[3]

Dr. Allen Thomson[4] corroborates the foregoing by a narrative obtained from an eye-witness : "While residing many years ago, during the summer months, at the baths of Sulla in Italy, in a somewhat damp locality, my informant, together with the rest of the family, was much annoyed by the frequent intrusion of small black scorpions into the house, and their being secreted among the bedclothes, in shoes, and other articles of dress. It thus became necessary to be constantly on the watch for these troublesome creatures, and to take means for their removal and destruction. Having been informed by the natives of the place that the scorpion would destroy itself if exposed to a sudden light, my informant and her friends soon became adepts in catching the scorpions and disposing of them in the manner suggested. This consisted in confining the animal under an inverted drinking-glass or tumbler, below which a card was inserted when the capture was made, and then, waiting till dark, suddenly bringing the light of a candle near to the glass in which the animal was confined. No sooner was this done than the scorpion invariably showed signs of great excitement, running round and round the interior of the tumbler with reckless velocity for a number of times. This state having lasted for a minute or more, the animal suddenly became quiet, and turning its tail on the hinder part of its body, over its back, brought its recurved sting down upon the middle of the head, and piercing it forcibly, in a few seconds became quite motionless, and in fact quite dead."

A consideration of the habits and peculiarities of the several spiders referred to constrains me to attribute to these creatures consciousness, volition, memory, and reason of a kind.

They are capable of profiting by experience, and can be educated up to a point. They can adapt means to ends. They are prescient, and store up food. They are affectionate, emotional, and, within limits, musical. They are mechanical, and construct their webs and nests on what might be considered strictly mathematical lines. They modify their constructions to suit altered conditions and circumstances. They can hunt on land and water, and lie in wait for prey, which they capture by strategy. Naturally of a fierce disposition, they can be tamed and rendered

[1] "Gleanings," vol. i., p. 103. [2] Romanes, "Animal Intelligence," p. 219. [3] *Nature*, vol. xi. [4] *Nature*, vol. xx., p. 577.

docile. Many of the attributes possessed by them are those found in the higher animals—man included. If to the foregoing be added the apparently now well-authenticated tendency to suicide or self-destruction by scorpions when greatly agitated and irritated by light and heat, the catalogue of attributes which they have in common with many of the higher animals is a long and important one. Of course it is not an uncommon thing for birds and dogs to commit suicide by refusing, under certain circumstances, to take food. Birds, when removed to strange places and uncongenial surroundings, frequently mope, sulk, and die of starvation. I had on one occasion a fine male swan presented to me by the proprietor of a large estuary in the south of Ireland, where the bird enjoyed the extreme of liberty, and flew about with numerous companions. The confinement of its new home was apparently wholly distasteful, and it absolutely refused to touch food, which was sedulously offered to it. It no doubt also missed its mates. It squatted on the lawn and refused to move, and looked the picture of misery. It died a few days after its arrival, of starvation. No more distressing or melancholy sight could be imagined. The large, noble, elegant white bird grew weaker and weaker, and ultimately its graceful head and neck sunk on its fair back, its wings slightly opened, and all was over.

The tendency of birds to refuse food and to pine and die is well known to the officials of the Zoological Gardens, London. When foreign and other birds arrive at the gardens the keepers are instructed to cram them with food until the sulking, desponding period passes off, and they become accustomed to isolation and confinement.

Dogs not unfrequently refuse food and die of starvation when separated from their masters and cherished homes. Suicide in the genus *homo* is unfortunately of frequent occurrence, and the tendency seems to increase in proportion to the degree of luxury and civilisation attained.

The spiders are endowed with a well-developed nervous system, consisting of a brain, which occupies the head, and furnishes nerves to the mandibles and organs of sense ; a thoracic ganglion which supplies nerves to the muscles of the thorax and limbs, and an abdominal ganglion which provides nerves to the intestine, &c. The nervous system is sufficiently developed to account for the many intellectual functions performed by them.

§ 255. The Ants.

In these small, active creatures, as likewise in bees and wasps, an intelligence in some respects superior to that witnessed in spiders is seen. In them, and also in bees and wasps, a complex social system is revealed, and the division of labour is carried out to quite an extraordinary extent. The individual lives for, and is sacrificed, if need be, to the body politic.

The ants have been a subject of study in all ages. Their amazing industry and thrift attracted the attention of the early observers, and, of late years, many important works and papers have been devoted to them.

Among the authorities who have sedulously studied and written upon ants may be mentioned Huber, Dujardin, Burmeister, Kirby and Spence, Franklin, Müller, Bates, Belt, MacCook, Moggridge, Lincecum, Lubbock, and Darwin.

While these authorities in some cases differ in matters of detail, they are unanimous in assigning to ants a high degree of intelligence. As a matter of fact, ants display many of the peculiarities which characterise man himself. They are gregarious, they build complicated nests for protection, they store food for the winter, they carry out the principle of the division of labour, they adapt themselves to circumstances, they display a knowledge of means to ends, they capture and employ slaves, they carry off and confine aphides which take the place of milch cows, they are endowed with sense organs and memory, and can recognise and remember each other ; they are emotional, and display extraordinary affection for their young, which they caress, tend, and nurse ; they can communicate with each other, and, in cases of danger and difficulty, the leaders consult and agree upon a common line of action. Certain of them make war upon their neighbours or amongst themselves, and their feuds and predatory excursions are carried out with a degree of skill and on a scale which at once excites the admiration and surprise of the beholder.

When we consider the comparatively small size of the great majority of ants, and contemplate the extremely minute dimensions of their nervous system, we are overwhelmed with a sense of their powers, actual and potential. Mr. Darwin regarded the brain of the ant as the most amazing piece of matter in the universe, and all thoughtful minds will readily concur in his estimate. His words are : " The brain of an ant is one of the most marvellous atoms of matter in the world, perhaps more so than the brain of a man." How an almost inappreciable speck of nervous matter can discharge a multiplicity of complex functions involving consciousness, memory, judgment, voluntary movement, adaptation of means to ends, &c., baffles the imagination. The fact that it does so invests living matter, especially brain matter, with a dignity, power, and importance all its own.

The tiny brain of the ant, composed of infinitely minute nerve cells, ganglia, and nerve fibres, throws a strong reflected light upon all brains up to that of man, upon the spinal cord when it exists, and upon collections of nerve

cells, ganglia, and nerve fibres, wherever found. It shows that infinitely minute portions of nerve substances are, or may be, charged with the initiation and direction of the most delicate, involved, and complex functions. It also shows that mere volume of nervous matter is not necessarily essential to important nervous manifestations. It makes for quality as against quantity, and carries out the idea that a small, richly convoluted, well-fed brain is often superior to a large, sparingly convoluted, badly fed one. It leads to the belief that small aggregations of nerve cells and ganglia where no brain exists, and in the spinal cord, from which the brain in the higher animals is developed, can, and do, discharge what are virtually brain functions.

Finally, it explains, in large measure, the God-like powers possessed by the great human brain, which, according to recent microscopic researches, consists of a congeries of the most highly-elaborated molecules, nerve cells, ganglia, and nerve fibres in existence.

In order that the reader may judge for himself as to the extraordinary powers possessed by ants, I append instances of their varied modes of working as supplied by veracious observers.

§ 256. The Sense Organs of Ants.

Ants see, hear, smell, and taste. They are also amenable to the sense of touch. When resting, ants, for the most part, live in the dark; when active they face any kind of light; they, however, prefer certain kinds of light to others. Thus Sir John Lubbock (Lord Avebury) found that under a slip of red glass in one of his artificial ants' nests there were congregated on one occasion 890 ants, under green 514, under yellow 495, and under violet only five.

"The coloured glasses appear to act on the ants in a graduated series, which corresponds with the order of their influence on a photographic plate; . . . the relative dislike to different colours seems to be determined by the position of the colour in the spectrum—there being a regular gradation of intolerance shown from the red to the violet end." Messrs. Moggridge and MacCook affirm that ants belonging to the genus *Atta* not only do not shun the light, but, on the contrary, seek and enjoy it, and come to the glass sides of their artificial nests to bask in the rays of a lamp.

Sir John Lubbock obtained a negative result as regards the hearing of ants, being unable to get them to respond to the vibrations of tuning-forks, violin and other strings, shouting, whistling, &c. Experiments with microphones and telephones also failed to attract their attention. Other observers were more fortunate, the highly sensitive antennæ responding, though not in a very marked manner.

Lubbock tested the sense of smell with a positive result by steeping a camel's-hair brush in strong scents and exposing it in the run of the ants. "Some went on without taking any notice, but others stopped, and evidently perceiving the smell turned back. In other cases the ants were observed to wave about and throw back their antennæ when the scented pencil was brought near. . . .

"The antennæ appear to be the most important of the sense organs, as their removal produces an extraordinary disturbance in the intelligence of the animal. An ant so mutilated can no longer find its way or recognise companions, and therefore is unable to distinguish between friends and foes. It is also unable to find food, ceases to engage in any labour, and loses all its regard for larvæ, remaining permanently quiet and almost motionless. A somewhat similar disturbance, or rather destruction, of the mental faculties is observable as a result of the same mutilation in the case of bees."

Huber was the first to point out that ants can smell, and that they track each other and discover food by this sense. If, says Huber, ants are following each other's trail they at once become disconnected and confused if a finger be drawn across the trail. The scent of the finger interferes with the scent of the ants themselves, and throws them out for the time. The confusion lasts only until the original scent is caught beyond the space covered by the trail of the finger.

Ants, as Lubbock shows, are more guided by smell than by sight, and cites experiments to prove the point.

"There can be little doubt that ants have a sense of taste, as they are so well able to distinguish sugary substances; and it is unquestionable that in their antennæ they possess highly elaborated organs of touch."

They are also credited with a sense of direction akin to that known to exist in "homing" animals.

That ants possess memory is attested by the observations of Mr. Belt on leaf-cutting ants. He found a nest of them in his garden, and drove them out by pouring a strong solution of carbolic acid into it. They migrated and disappeared for a year. At the end of that time, and when the carbolic acid had dried up and evaporated, they returned to the old nest and reoccupied it. Herr Karl Vogt (in his "Thierstaaten") also mentions "that for several successive years ants from a certain nest used to go through certain inhabited streets to a chemist's shop 600 metres distant, in order to obtain access to a vessel filled with syrup. As it cannot be supposed that this vessel was found

in successive working seasons by as many successive accidents, it can only be concluded that the ants remembered the syrup store from season to season."

Ants display great anxiety and tenderness for their young, which they tend with devotion and solicitude in times of peace, and promptly remove in times of danger. They also in some cases exhibit marked sympathy and distress when their fellows are overtaken by an unlooked-for calamity. When certain ants are crushed accidentally or intentionally their fellows become perturbed, rush wildly about, and in many cases beat a hasty retreat. If an ant be mutilated, placed beneath a stone, or partially buried, its friends come to the rescue. All ants are not equally emotional and sympathetic. Lubbock experimented with ants which, according to him, were deficient both in affection and in their desire to help others. Thus he found that when healthy ants were entangled in honey their friends regaled themselves with the sweet fluid and made no efforts to rescue them. When ants were chloroformed they were treated as dead and extruded from the nest. When intoxicated they were carried into the nest of the same community, and extruded if they belonged to another community. Lubbock quotes Latreille to the effect that ants display sympathy with mutilated companions, and mentions a case in his own experience. "A specimen of *F. fusca* congenitally destitute of antennæ was attacked and injured by an ant of another species. When separated, another ant of her own species came by. 'She examined the poor sufferer carefully, then picked her up tenderly, and carried her away into the nest. It would have been difficult for any one who witnessed this scene to have denied to this ant the possession of humane feelings.'"

Belt, with a view to testing the sympathetic side of the ant, made the following experiments:[1] "One day, watching a small column of these ants (*i.e.*, *Eciton hamata*), I placed a little stone on one of them to secure it. The next that approached, as soon as it discovered its situation, ran backwards in an agitated manner, and soon communicated the intelligence to the others. They rushed to the rescue; some bit at the stone and tried to move it, others seized the prisoner by the legs and tugged with such force that I thought the legs would be pulled off, but they persevered until they got the captive free. I next covered one up with a piece of clay, leaving only the ends of its antennæ projecting. It was soon discovered by its fellows, which set to work immediately, and by biting off pieces of the clay soon liberated it. Another time I found a very few of them passing along at intervals. I confined one of these under a piece of clay at a little distance from the line, with his head projecting. Several ants passed it, but at last one discovered it and tried to pull it out, but could not. It immediately set off at a great rate, and I thought it had deserted its comrade, but it had only gone for assistance, for in a short time about a dozen ants came hurrying up, evidently fully informed of the circumstances of the case, for they made directly for their imprisoned comrade and soon set him free. I do not see how this action could be instinctive. It was sympathetic help, such as man only among the higher mammalia shows. The excitement and ardour with which they carried on their unflagging exertions for the rescue of their comrade could not have been greater if they had been human beings."

From the foregoing experiments performed by Belt it will be seen that ants have the power of communicating with each other. They do so in many ways and in all the ordinary concerns of life. They communicate with each other in collecting and storing food, in building their nests, in tending their young, in their fights with each other (internecine and other wars), in their capture of aphides and slaves, in their marital arrangements, &c.

A power of communication is a *sine qua non* in every social community, and the ants form no exception. The division of labour which obtains in every ants' nest makes this faculty imperative. Wherever there are large collections of individuals living under the same roof or in the same city or territory, there must be a system of signs, signals, and means whereby orders can be given, received, and acted on. An ants' nest would be confusion worse confounded if each ant acted independently and for its own benefit, instead of in concert and for the good of the body politic.

Unity is strength, and ants are formidable because they act shoulder to shoulder and to given ends.

In an ant community there are parents, nurses, workers, warriors, slaves, architects, &c., each one helping the other.

"The eggs will not develop into larvæ unless nursed. The nursing is effected by licking the surface of the eggs, which under the influence of this process increase in size, or grow. In about a fortnight, during which time the workers carry the eggs from higher to lower levels of the nest, and *vice versâ*, according to the circumstances of heat, moisture, &c., the larvæ are hatched out, and require no less careful nursing than the eggs. The workers feed them by placing mouths together and regurgitating food stored up in the crop or proventriculus into the intestinal tract of the young. The latter show their hunger by 'stretching out their little brown heads.' Great care is also taken by the workers in cleaning the larvæ, as well as in carrying them up and down the chambers of the nest for warmth or shelter.

"When fully grown the larvæ spin cocoons, and are then pupæ, or the ants' eggs of bird-fanciers. These

[1] "The Naturalist in Nicaragua," 1874, p. 26.

require no food, but still need incessant attention with reference to warmth, moisture, and cleanliness. When the time arrives for their emergence as perfect insects, the workers assist them to get out of their larval cases by biting through the walls of the latter. It is noticeable that in doing this the workers do not keep to any exact time, but free them sometimes earlier and sometimes later, in accordance with their rate of development."[1]

Herr Büchner[2] adds: "The little animal, when freed from its chrysalis, is still covered with a thin skin, like a little shirt, which has to be pulled off. When we see how neatly and gently this is done, and how the young creature is then washed, brushed, and fed, we are involuntarily reminded of the nursing of human babies. The empty cases, or cocoons, are carried outside the nest, and may be seen heaped together there for a long time. Some species carry them far away from the nest, or turn them into building materials for the dwelling."

The young ants have to be educated so as to perform their respective parts in what is virtually a very complex system. "The young ants are led about the nest, and 'trained to a knowledge of domestic duties, especially in the case of the larvæ.' Later on the young ants are taught to distinguish between friends and foes. When an ants' nest is attacked by foreign ants, the young ones never join in the fight, but confine themselves to removing the pupæ; and that the knowledge of hereditary enemies is not wholly instinctive in ants is proved by the following experiment, which we owe to Forel. He put young ants belonging to three different species into a glass case with pupæ of six other species—all the species being naturally hostile to one another. The young ants did not quarrel, but worked together to tend the pupæ. When the latter hatched out, an artificial colony was formed of a number of naturally hostile species all living together after the manner of the 'happy families' of the showman."[3]

Forel's experiment clearly shows that ants of different species do not at the outset entertain feelings of hostility to each other, and that such feelings are developed later by their seniors, who foster class or racial hatred, as in the several races of mankind. The fact that ants can be taught involves powers of initiative, memory, and the ability to profit by experience.

The manner in which ants capture and keep aphides and slaves is at once interesting and instructive.

Huber showed that the ants collect the eggs of the aphides and treat them exactly as they do their own, guarding and tending them with the greatest assiduity. "When these eggs hatch out the aphides are usually kept and fed by the ants, to whom they yield a sweet honey-like food, which they eject from the abdomen upon being stroked on this region by the antennæ of the ants."[4] The aphides are to ants what the milch cow is to man. Not only do ants collect and hatch out and feed the aphides, but they build stalls for and house them most carefully. They even in certain cases make covered ways between their nests and the trees and plants in which the aphides live. "Forel saw a tunnel of this kind which was taken up a wall and down again on the other side, in order to secure a safe covered way from the nest to the aphides. Occasionally such covered ways, or tubes, are continued so as to enclose the stems of the plants on which the aphides live. The latter are thus imprisoned by the walls of the tube, which, however, expand where they take on this additional function of stabling the aphides, so that these insects are really confined in tolerably large chambers." The ants go even further. They secure and carry the eggs of the aphides to their nests, protect them from cold during the winter, and return them to their feeding ground in the trees in summer. They literally farm the aphides. They also farm other insects which yield sweet secretions, such as gall insects, cocci, caterpillars, &c. MacCook remarks that when gall insects and cocci are employed as cows they are kept in separate stalls. All this bespeaks a knowledge of means to ends and intelligence of a high order.

The slave-raiding propensities of certain ants, and their employment of slave labour, furnish a very remarkable chapter in their history. The subjugation and domination of one species over another is of great significance psychologically.

War as waged by ants implies not only valour but strategy and generalship, and the conversion of a defeated foe into slaves bespeaks resolve, reflection, and judgment; the fruits of victory are utilised as thoroughly as in African and other barbaric conflicts.

According to Büchner, "the ants have no regular leaders nor chiefs, yet it is certain that in each expedition, alteration of road, or other change, the decision during that event comes from a small knot of individuals, which have previously come to an understanding, and carry the rest and the undecided along with them. These do not always follow immediately, but only after they have received several taps on the head from the members of the 'ring.' The procession does not advance until the leaders have convinced themselves by their own eyesight that the main part of the army is following."

Forel thus describes a battle between the Amazons and the *F. rufibarbis*, a sub-species of the *F. fusca*:[5] "The vanguard of the robber army found that it had reached the neighbourhood of the hostile nest more quickly

[1] Romanes, "Animal Intelligence," p. 58.
[2] "Geistesleben der Thiere," pp. 66, 67.
[3] Romanes, "Animal Intelligence," p. 59.
[4] Op. cit., pp. 60, 61.
[5] Op. cit., p. 71.

than it had expected; for it halted suddenly and decidedly, and sent a number of messengers which brought up the main body and the rearguard with incredible speed. In less than thirty seconds the whole army had closed up, and hurled itself in a mass on the dome of the hostile nest. This was the more necessary as the *rufibarbis* during the short halt had discovered the approach of the enemy, and had utilised the time to cover the dome with defenders. An indescribable struggle followed, but the superior numbers of the Amazons overcame, and they penetrated into the nest, while the defenders poured by thousands out of the same holes, with their larvæ and pupæ in their jaws, and escaped to the nearest plants and bushes, running over the heaps of their assailants. These looked on the matter as hopeless, and began to retreat. But the *rufibarbis*, furious at their proceedings, pursued them, and endeavoured to get away from them the few pupæ they had obtained, by trying to seize the Amazons' legs and to snatch away the pupæ." . . . "In the above case the strength of the *rufibarbis* proved at last so great that the rearguard of the retreating army was seriously pressed, and was obliged to give up its booty. A number of the Amazons also were overpowered and killed, but not without the *rufibarbis* also losing many of their number. None the less did some individuals, as though desperate, rush into the thickest hosts of the enemy, penetrated again into the nest, and carried off several pupæ by sheer audacity and skill. Most of them left their prey to go to the help of their comrades when assailed by the *rufibarbis*. Ten minutes after the commencement of the retreat all the Amazons had left the nest, and, being swifter than their opponents, they were only pursued for about halfway back. Their attack had failed on account of a short delay."

One can readily understand how one animal captures and destroys another animal for food, but to capture, subjugate, retain, and employ as slaves indicates a degree of mental capacity and intelligence which it is difficult to realise. It is scarcely possible to deny to ants a certain order of mind.

There are at least three kinds of slave-making ants, namely, *Formica rufescens*, *F. sanguinea*, and *Strongylognathus*.

P. Huber discovered the habit in the first-named species. "Here the species enslaved is *F. fusca*, which is appropriately coloured black. The slave-making ants attack a nest of *F. fusca* in a body; there is a great fight with much slaughter, and, if victorious, the slave-makers carry off the pupæ of the vanquished nest in order to hatch them out as slaves."

The following summing up of the relations between two of the slave-making species of ants, *F. sanguinea* and *F. rufescens*, is given by Darwin:[1] "The latter does not build its own nest, does not determine its own migrations, does not collect food for itself or for its fellows, and cannot even feed itself; it is absolutely dependent on its numerous slaves. *Formica sanguinea*, on the other hand, possesses much fewer slaves, and in the early part of the summer extremely few; the masters determine when and where a new nest shall be formed, and when they migrate, the masters carry the slaves. Both in Switzerland and England the slaves seem to have the exclusive care of the larvæ, and the masters alone go on slave-making expeditions. In Switzerland the slaves and masters work together, making and bringing materials for the nest; both, but chiefly the slaves, tend and milk, as it may be called, their aphides; and thus both collect food for the community. In England the masters alone usually leave the nest to collect building materials and food for themselves, their slaves, and larvæ; so that the masters in this country receive much less service from their slaves than they do in Switzerland."

It has been suggested by Darwin that the slave-making habit may have originally had its origin in ants carrying off the pupæ of other ants for food, certain of these pupæ having been overlooked and surviving to render service to their cannibal masters.

This view seems negatived by the fact that other insects besides ants are employed as slaves.

"According to Audubon certain leaf-bugs are used as slaves by the ants in the Brazilian forests. When these ants want to bring home the leaves which they have bitten off the trees, they do it by means of a column of these bugs, which go in pairs, kept in order on either side by accompanying ants. They compel stragglers to re-enter the ranks, and laggards to keep up by biting them. After the work is done the bugs are shut up within the colony and scantily fed."[2]

The building operations of ants are characterised by much originality, ingenuity, and adaptive skill. They clearly indicate a knowledge of means to ends. Forel points out that "the characteristic *trait* of the building of ants is the almost complete absence of an unchangeable model, peculiar to each species, such as in wasps, bees, and others. The ants know how to suit their indeed little perfect work to circumstances, and to take advantage of each situation. Besides, each works for itself and on a given plan, and is only occasionally aided by others when these understand its plan. Naturally many collisions occur, and some destroy that which others have made. This also gives the key to understanding the labyrinth of the dwelling. For the rest, it is always those workers which have discovered the most advantageous method, or which have shown the most patience, which win over to their plan the majority of their comrades."[2]

[1] "Origin of Species," 6th edition, p. 218.

[2] Romanes, "Animal Intelligence," pp. 68, 129.

P. Huber records a striking example of an important alteration in the construction of a wall and arched roof forming part of an ants' nest. "A wall had been partly erected by the ants as though it were intended to support the still unfinished arched roof of a large room, which was being built from the opposite side. But the workers which had begun the arch had given it too low an elevation for the wall on which it was to rest, and if it had been continued on the same lines it would have met the partition wall halfway up; and this was to be avoided. I had just made this criticism to myself, when a new arrival, after looking at the work, came to the same conclusion, for it began at once to destroy what had been done, and to heighten the wall on which it was supported, and to make a new arch with the materials of the old one, under my very eyes."

M. Ebrard[1] chronicles a case displaying consummate mechanical skill in *F. fusca:* "The earth was damp and the workers were in full swing. It was a constant coming and going of ants, coming forth from their underground dwelling, and carrying back little pellets of earth for building. . . . The work had made considerable progress; but although a projection could be plainly seen along the upper edge of the wall of the largest of the rooms, there remained an interspace of about twelve or fifteen millimetres to fill in. Here would have been the place, in order to support the earth still to be brought in, to have had recourse to those pillars, buttresses, or fragments of dried leaves which many ants are wont to use in building. But the use of this expedient is not customary with the ants I was observing (*F. fusca*). Our ants, however, were sufficient for the occasion. For a moment they seemed inclined to leave their work, but soon turned instead to a grass-plant growing near, the long narrow leaves of which ran close together. They chose the nearest, and weighted its distal end with damp earth, until its apex just bent down to the space to be covered. Unfortunately the bend was too close to the extremity, and it threatened to break. To prevent this misfortune, the ants gnawed at the base of the leaf until it bent along its whole length and covered the space required. But as this did not seem to be quite enough, they heaped damp earth between the base of the plant and that of the leaf, until the latter was sufficiently bent. After they had thus attained their object, they heaped on the buttressing leaf the materials required for building the arched roof."

Mr. MacCook also records a case of mechanical ingenuity as follows:[2] "Here I observed what appeared to be a new mode of operation. The workers, in several cases, left the point at which they had begun a cutting, ascended the blade, and passed as far out toward the point as possible. The blade was thus borne downward, and as the ant swayed up and down it really seemed that she was taking advantage of the leverage thus gained, and was bringing the augmented force to bear upon the fracture. In two or three cases there appeared to be a division of labour; that is to say, while the cutter at the roots kept on with her work, another ant climbed the grass blade and applied the power at the opposite end of the lever. This position may have been quite accidental, but it certainly had the appearance of a voluntary co-operation."

Moggridge, in speaking of European harvesting ants, describes the manner in which they remove the roots of plants which pierce their galleries. The operation was performed by two ants acting in concert, "one pulling at the free end of the root, and the other gnawing at its fibres where the strain was greatest, until at length it gave way." He adds: "Two ants sometimes combine their efforts, when one stations itself near the base of the peduncle, and gnaws it at the point of greatest tension, while the other hauls upon and twists it. . . . I have occasionally seen ants engaged in cutting the capsules of certain plants, drop them, and allow their companions below to carry them away."

Almost more remarkable is the account given by Mr. Bingley[3] of the green ants of New South Wales seen by Sir Joseph Banks in Captain Cook's expedition.

"The green ants live upon trees, and build their nests of various sizes, between that of a man's head and his fist. These nests are of a very curious structure; they are formed by bending down several of the leaves, each of which is as broad as a man's hand, and gluing the points of them together so as to form a purse. The viscous matter used for this purpose is an animal juice. . . . Their method of bending down leaves we had no opportunity to observe; but we saw thousands uniting all their strength to hold them in this position, while other busy multitudes were employed within, in applying this gluten, that was to prevent their returning back. To satisfy ourselves that the leaves were bent and held down by the efforts of these diminutive artificers, we disturbed them in their work; and as soon as they were driven from their station, the leaves on which they were employed sprang up with a force much greater than we could have thought them able to conquer by any combination of their strength."

Sir E. Tennent attributes analogous powers to the great red ant (*Dimiya*) frequenting the fruit trees of gardens. It constructs its dwellings by gluing the leaves of such species as are suitable from their shape and pliancy into hollow balls, and these it lines with a kind of transparent paper, like that manufactured by the wasp. I have watched them at the interesting operation of forming these dwellings. "A line of ants standing on the edge of one leaf brings another into contact with it, and hold both together with their mandibles till their companions

[1] "Etudes de Mœurs," p. 3. [2] Romanes, "Animal Intelligence," p. 132. [3] "Animal Biography," Ants.

within attach them firmly by means of their adhesive paper, the assistants outside moving along as the work proceeds. If it be necessary to draw closer a leaf too distant to be laid hold of by the immediate workers, they form a chain by depending one from the other till the object is reached, when it is at length brought into contact, and made fast by cement."

The resource of ants in overcoming difficulties in securing food almost passes belief.

Réaumur[1] as early as 1734 recorded a remarkable example communicated to him by Cardinal Fleury. "The cardinal smeared the trunk of a tree with bird-lime in order to prevent the ants from ascending it; but the insects overcame the obstacle by making a road of earth, small stones, &c. In another instance the cardinal saw a number of ants make a bridge across a vessel of water surrounding the bottom of an orange-tree tub. They did so by conveying a number of little pieces of *wood*, the choice of which material instead of earth or stones, as in the previous case, seems to betoken no small knowledge of practical engineering."

Leuckart, as Romanes informs us (p. 135), "placed round the trunk of a tree, which was visited by ants as a pasture for aphides, a broad cloth soaked in tobacco-water. When the ants returning home down the trunk of the tree arrived at the soaked cloth, they turned round, went up the tree again to some of the overhanging branches, and allowed themselves to drop clear of the obnoxious barrier. On the other hand, the ants which desired to mount the tree first examined the nature of the barrier, then turned back and procured from a distance little pellets of earth, which they carried in their jaws and deposited one after another upon the tobacco-cloth till a road of earth was made across it, over which the ants passed to and fro with impunity."

Similar testimony is borne by Sykes, of ants at Poona, in their attempts to pilfer the dessert of fruits, cakes, and preserves. To prevent the pillage the legs of the table on which the dessert was placed were immersed in four basins filled with water; the table itself being removed an inch from the wall. The plan succeeded only for a short time; the ants, at the risk of being drowned, crossing the water. The legs of the table were then painted with a ring of turpentine above the water. This ruse succeeded for several days, but was then discovered, when the ants reappeared. They were seen to clamber up the wall next the table for a foot or so, when with a jerk they precipitated themselves from the wall on to the table.

Herr Büchner[2] records a case of still more amazing resource on the part of the ants: "A maple tree standing on the ground of the manufacturer, Volbaum, of Elbing (now of Dantzic), swarmed with aphides and ants. In order to check the mischief, the proprietor smeared about a foot width of the ground round the tree with tar. The first ants who wanted to cross naturally stuck fast. But what did the next? They turned back to the tree and carried down aphides, which they stuck down on the tar one after another until they had made a bridge over which they could cross the tarring without danger."

Herr Karl Vogt[3] states that in the case of a bee-hive invaded by ants the proprietor inserted the legs of the bee-hive stand in shallow basins of water, and so prevented the ingress of the ants. The ants, not to be done, crept up a linden tree, the branches of which overhung the hive. They then deliberately dropped on the hive, and so secured their feed of honey. On one occasion the water in one of the basins dried up, whereupon the ants swarmed into the basin. Their progress was checked by the leg of the table occupying the dried basin not reaching it by about half an inch. The ants held a consultation, rapidly touching each other with their antennæ. Presently a large ant came forward and reared itself on its hind legs, managing to seize by its fore legs a projecting splinter of wood. Others at once availed themselves of the living bridge thus produced. They also strengthened the bridge by joining together and taking additional holds. Karl Vogt cites another and even more remarkable case, where an accidental straw in one of the vessels of water in which one of the legs of a cupboard was immersed afforded a temporary bridge. He pushed the straw about an inch away from the cupboard. "A terrible confusion arose. In a moment the leg immediately over the water was covered with hundreds of ants, feeling for the bridge in every direction with their antennæ, running back again and coming in ever larger swarms, as though they had communicated to their comrades within the cupboard the fearful misfortune that had taken place. Meanwhile the newcomers continued to run along the straw, and not finding the leg of the cupboard the greatest perplexity arose. They hurried round the edge of the pan, and soon found out where the fault lay. With united forces they quickly pulled and pushed at the straw, until it again came into contact with the wood, and the communication was again restored."

Mr. Belt confirms in a striking manner the powers of observation, reasoning, and adaptation which obtain in ants. Referring to the leaf-cutting ants of South America he says: "A nest was made near one of our tramways, and to get to the trees the ants had to cross the rails, over which the waggons were continually passing and repassing. Every time they came along a number of ants were crushed to death. They persevered in crossing for some time, but at last set to work and tunnelled underneath each rail. One day, when the waggons were not

[1] "L'Histoire des Insectes." [2] Loc. cit., p. 120. [3] Loc. cit., p. 128.

running, I stopped up the tunnels with stones; but although great numbers carrying leaves were thus cut off from the nest, they would not cross the rails, but set to work making fresh tunnels underneath them."

Speaking of the Ecitons he adds: "I shall relate two more instances of the use of a reasoning faculty in these ants. I once saw a wide column trying to pass along a crumbling, nearly perpendicular slope. They would have got very slowly over it, and many of them would have fallen, but a number, having secured their hold, and reaching to each other, remained stationary, and over them the main column passed. Another time they were crossing a watercourse along a small branch, not thicker than a goose-quill. They widened this natural bridge to three times its width by a number of ants clinging to it and to each other on each side, over which the column passed three or four deep; whereas, excepting for this expedient, they would have had to pass over in single file, and treble the time would have been consumed. Can it be contended that such insects are not able to determine by reasoning powers which is the best way of doing a thing?"

Numerous other examples of adaptation and of the employment of means to ends might be adduced, all illustrating in a marked manner the possession of reasoning power by ants. These powers are also attested in other directions.

Ants clean and groom each other; they ventilate their dwellings and remove from them everything which is calculated to make them insanitary. Thus they carry off their dead, and whatever is likely to decay, to a distance. In collecting seeds for food they not only pick them off the ground, but they ascend plants, shrubs, and trees, and harvest them. In these operations they sometimes throw them down to be picked up by others in preference to ascending and descending themselves, and so save time and tissue. If certain of the seeds become damp they take them out of the nest and dry them. It is even stated that they sow seeds, and raise near their nests a plant known as "ant rice," of which they are very fond. It is known that the leaf-cutting ants do not eat the portions of the leaves they cut, but that these are placed in the nest, and form a plant mould in which a delicate fungus grows which is a favourite food. Ants make pets of small beetles and crickets. They cross small rivers by the aid of tiny pieces of wood, which they employ as rafts. "If no natural bridge be available for the passage, they travel along the bank of the river until they arrive at the flat, sandy shore. Each ant now seizes a bit of dry wood, pulls it into the water, and mounts thereupon. The hinder rows push the front ones even further out, holding on to the wood with their feet and to their comrades with their jaws. In a short time the water is covered with ants, and when the raft has grown too large to be held together by the small creatures' strength, a part breaks itself off and begins the journey across, while the ants left on the bank busily pull their bits of wood into the water, and work at enlarging the ferry-boat until it again breaks. This is repeated as long as an ant remains on the shore."

Romanes[1] gives a graphic account of the depredations of the foraging ant (military ant of the Amazon): "The *Eciton legionis* moves in enormous armies, and everything that these insects do is done with the most perfect instinct of military organisation. The army marches in the form of a rather broad and regular column, hundreds of yards in length. The object of the march is the capture and plunder of other insects, &c., for food, and as the well-organised host advances, its devastating legions set all other terrestrial life at defiance. From the main column there are sent out smaller lateral columns, the composing individuals of which play the part of scouts, branching off in various directions, and searching about with the utmost activity for insects, grubs, &c., over every log, under every fallen leaf, and in every nook and cranny where there is any chance of finding prey. When their errand is completed, they return into the main column. If the prey found is sufficiently small for the scouts themselves to manage, it is immediately seized, and carried back to the main column; but if the amount is too large for the scouts to deal with alone, messengers are sent back to the main column, whence there is immediately dispatched a detachment large enough to cope with the requirements. Insects which when killed are too large for single ants to carry, are torn in pieces, and the pieces conveyed back to the main army by different individuals. Many insects, in trying to escape, run up bushes and shrubs, where they are pursued from branch to branch and twig to twig by their remorseless enemies, until on arriving at some terminal ramification they must either submit to immediate capture by their pursuers, or drop down amid the murderous hosts beneath. All the spoils that are taken by the scouts, or by the detachments sent out in answer to their demands for assistance, are immediately taken back to the main column. When they arrive there, they are taken to the rear of that column by two smaller columns of carriers, which are constantly running, one on either side of the main column, with the supplies that are constantly pouring in from both sides. Each of these outside columns is a double line, the ants composing one of the two lines all running in the same direction as the main army, and the ants composing the other line all running in the opposite direction. The former are empty-handed carriers, which having deposited their burdens in the rear, are again advancing to the van for fresh burdens. Those composing the other line are all laden with

[1] "Animal Intelligence." London, 1898, pp. 114, 115, and 116.

the mangled remains of insects, pupæ of other ants, &c. On either side of the main column there are also constantly running up and down a few individuals of smaller size and lighter colour than the other ants, which seem to play the part of officers; for they never leave their stations, and while running up and down the outsides of the column, they every now and again stop to touch antennæ with some member of the rank and file, as if to give instructions. When the scouts discover a wasp's nest in a tree, a strong force is sent out from the main army, the nest is pulled to pieces, and all the larvæ carried to the rear of the army, while the wasps fly round defenceless against the invading multitude. Or, if the nest of any other species of ant is found, a similarly strong force, or perhaps the whole army, is deflected towards it, and with the utmost energy the innumerable insects set to work to sink shafts and dig mines till the whole nest is rifled of its contents. In these mining operations the ants work with an extraordinary display of organised co-operation; for those low down in the shafts do not lose time by carrying up the earth which they excavate, but pass on the pellets to those above; and the ants on the surface, when they receive the pellets, carry them 'with an appearance of forethought that quite staggered' Mr Bates, only just far enough to ensure that they shall not roll back again into the shaft, and, after depositing them, immediately hurry back for more. But there is not a rigid division of labour, although the work 'seems to be performed by intelligent co-operation amongst a host of eager little creatures;' for some of them act 'sometimes as carrier of pellets, and at another as miners, and all shortly afterwards assume the office of conveyors of the spoil.'"

I myself can testify to the powers of co-operation in ants. On one occasion in the Lower Engadine, Switzerland, I saw a small army of ants carrying to their nest a mutilated, half-dead, large butterfly. On another occasion I saw a still larger army of ants hauling along an earthworm the length of my middle finger. They worked and rested by turns, and the worm was dragged to the nest in a surprisingly short time. That the ants should have attempted and succeeded in such herculean tasks greatly surprised and impressed me.

The Eciton ants pursue a nomadic life. They have no nests like other ants, and are ever on the march, marauding and campaigning. At night they halt, close up, and form a camp. Next morning finds them abroad and on the warpath. The larger species of Eciton (*E. hamata*) according to Belt are of various sizes; the smaller ants (the workers) going into the smallest orifices and holes and ferreting out everything. These Ecitons sometimes hunt in skirmishing order and sometimes in columns, according to the kind of prey sought for. "When a nest of the *Hypoclinea* is attacked, the ants rush out, carrying the larvæ and pupæ in their jaws, but are immediately despoiled of them by the Ecitons, which are running about in every direction with great swiftness. . . . As soon as an Eciton gets hold of its prey, it rushes off back along the advancing column, which is composed of two sets, one hurrying forwards, the other returning laden with their booty, but all and always in the greatest haste and apparent hurry. About the nest which they are harrying all appears in confusion, Ecitons running here and there and everywhere in the greatest haste and disorder; but the result of all this apparent confusion is that scarcely a single *Hypoclinea* gets away with a pupa or larva. I never saw the Ecitons injure the *Hypoclineas* themselves, they were always contented with despoiling them of their young." . . . "The eyes in the Ecitons are very small, in some of the species imperfect, and in others entirely absent; in this they differ greatly from the *Pseudomyrma* ants, which hunt singly and which have the eyes greatly developed. The imperfection of eyesight in the Ecitons is an advantage to the community, and to their particular mode of hunting. It keeps them together, and prevents individual ants from starting off alone after objects that, if their eyesight was better, they might discover at a distance; the Ecitons and most other ants follow each other by scent, and, I believe, they can communicate the presence of danger, of booty, or other intelligence, to a distance by the different intensity or qualities of the odours given off. . . . At one point I noticed a sort of assembly of about a dozen individuals that appeared in consultation. . . . Here and there one of the light-coloured officers moves backwards and forwards directing the columns. Such a column is of enormous length, and contains many thousands if not millions of individuals. I have sometimes followed them up for two or three hundred yards without getting to the end.

"They make their temporary habitations in hollow trees, and sometimes underneath large fallen trunks that offer suitable hollows. A nest that I came across in the latter situation was open at one side. The ants were clustered together in a dense mass, like a great swarm of bees, hanging from the roof but reaching to the ground below. . . . The mass, which must have been at least a cubic yard in bulk, contained hundreds of thousands of individuals, although many columns were outside, some bringing in the pupæ of ants, others the legs and dissected bodies of various insects. I was surprised to see in this living nest tubular passages leading down to the centre of the mass, kept open just as if it had been formed of inorganic materials. Down these holes the ants who were bringing in booty passed with their prey. . . . Besides the common dark-coloured workers and light-coloured officers, I saw here many still larger individuals with enormous jaws. These they go about holding wide open in a threatening manner."

The marauding ants of the Amazon display an amazing amount of intelligence of a kind. Like other robbers,

they must possess superior wit to outwit the creatures on which they prey. This is in accordance with facts furnished by the higher animals. Wild animals have as a rule larger brains than domestic animals—this is especially true of birds—and beasts of prey have larger brains than the animals hunted. The hunters must be able to circumvent their quarry. Man is the greatest of all hunters, and his brain, as is well known, is the largest of all brains relatively to the weight of the body.

§ 257. The Termites.

Before leaving the subject of ants it may be well to direct attention very briefly to the white ants, the history of which is imperfectly known.

The intelligence of these extraordinary creatures is perhaps seen to most advantage in their buildings or nests, which are at once very complicated, extensive, and strong.

In Africa,[1] where the termites abound, the nests are conical in shape, and from ten to twenty feet high. They increase in size according to the age and strength of the colony, and are composed of bits of wood, small stones, earth, and other material firmly glued together by a kind of saliva which they secrete. The strength of the nests is such that they can support a buffalo or other large animal without being crushed. They are built on a regular plan; the plan being modified in certain cases to meet unlooked-for conditions. Usually the nest consists of a series of tunnels or roadways, a foot or so in breadth, which radiate from the centre of the cone. To these are added a complicated system of tubes which assist in ventilating the nest, and carry off any water which may be discharged upon it by sudden tropical rains.

The white ants differ from the majority of ants already described in being blind. Their habitations are therefore reared, and all their operations conducted, in the dark. Their want of eyes constrains them to work as a rule from within outwards and to construct tunnels which screen them from observation. If fruit or other edible substance is to be devoured or carried off, it is attacked at the point where it touches the ground.

The white ants, like many of the tree ants, are divided into workers and warriors. The workers build the nest, forage for food, feed the young, and perform all kinds of menial and necessary labour: the warriors guard the nest and all it contains. The warrior ants are larger than the workers, and are provided with formidable, powerful jaws which they employ to good purpose, and with which they menace all intruders. They are tenacious and vicious to a degree. If they once lay hold of an enemy they suffer themselves to be torn to pieces rather than let go.

Büchner gives the following interesting account of their nests and habits:[2] "There are myriads of rooms, cells, nurseries, provision chambers, guard-rooms, passages, corridors, vaults, bridges, subterranean streets and canals, tunnels, arched ways, steps, smooth inclines, domes, &c., &c., all arranged on a definite, coherent, and well-considered plan. In the middle of the building, sheltered as far as possible from outside dangers, lies the stately royal dwelling, resembling an arched oven, in which the royal pair reside, or rather are imprisoned; for the entrances and outlets are so small, that although the workers on service can pass easily in and out, the queen cannot; for during the egg-laying her body swells out to an enormous size, two or three thousand times the size and weight of an ordinary worker. The queen, therefore, never leaves her dwelling, and dies therein. Round the palace, which is at first small, but is later enlarged in proportion as the queen increases in size until it is at least a yard long and half a yard high, lie the nurseries, or cells for the eggs and larvæ; next these the servants' rooms, or cells for the workers which wait on the queen; then special chambers for the soldiers on guard, and, between these, numerous store-rooms, filled with gums, resins, dried plant-juices, meal, seeds, fruits, worked-up wood, &c. According to Bettziech-Beta, there is always in the midst of the nest a large common room, which is used either for popular assemblies or as the meeting and starting point of the countless passages and chambers of the nest. Others are of opinion that this space serves for purposes of ventilation.

"Above and below the royal cell are the rooms of the workers and soldiers which are specially charged with the care and defence of the royal pair. They communicate with each other, as well as with the nursery-cells and store-rooms, by means of galleries and passages, which, as already said, open into the common room in the middle under the dome. This room is surrounded by high, boldly projected arched ways, which lose themselves further out in the walls of the countless rooms and galleries. Many roofs, outside and in, protect this room and the surrounding chambers from rain, which, as already said, is drained away by countless subterranean canals, made of clay and of a diameter of ten or twelve centimetres. There are also, under the layer of clay covering the whole building, broad spirally winding pasages running from below to the highest points, which communicate with the

[1] *Vide* "History of Gambia," by Jobson; "The Nations of Eastern Asia," by Bastian; and *Phil. Trans.*, vol. lxxi., paper by Smeathman.
[2] Büchner's "Geistesleben der Thiere," pp. 194 and 199–200.

passages of the interior, and apparently, as they mainly consist of smooth inclines, serve for carrying provisions to the highest parts of the nest. . . . If an attack is made, and the assailant withdraws beyond the reach of the warriors and inflicts no further injury, they retire within their dwelling in the course of half an hour, as though they had come to the conclusion that the enemy who had done the mischief had fled. Scarcely have the soldiers disappeared when crowds of workers appear in the breach, each with a quantity of ready-made mortar in its mouth. As soon as they arrive they stick this mortar round the open place, and direct the whole operation with such swiftness and facility that in spite of their great number they never hinder each other, nor are obliged to stop. During this spectacle of apparent restlessness and confusion the observer is agreeably surprised to see arising a regular wall, filling up the gap. During the time that the workers are thus busied the soldiers remain within the nest, with the exception of a few, which walk about apparently idly, never touching the mortar, among the hundreds and thousands of workers. Nevertheless one of them stands on guard close to the wall which is being built. It turns gently each way in turn, lifting its head at intervals of one or two minutes to strike the building with its heavy mandibles, making the before-mentioned crackling noise. This signal is immediately answered by a loud rustling from the interior of the nest and from all the subterranean passages and holes. There is no doubt that this noise arises from the workers, for as often as the sign is given they work with increased energy and speed. A renewal of the attack instantaneously changes the scene. 'At the first stroke,' says Smeathman, 'the workers run into the many tunnels and passages which run through the building, and this happens so quickly that they seem regularly to vanish.' In a few seconds they are all gone, and in their stead appear the soldiers once more, as numerous and as pugnacious as before. If they find no enemy, they turn back slowly into the interior of the hill, and immediately the mortar-laden workers again appear, and among them a few soldiers, which behave just as on the first occasion. So one can have the pleasure of seeing them work and fight in turn, as often as one chooses ; and it will be found each time that one set never fight, and the other never work, however great the need may be.

"The white ants make all their expeditions by the aid of underground passages. If they encounter a rock or other impenetrable substance they erect a tubular passage upon its surface. They can even carry their viaducts through the air, and that in such bold arches that it is difficult to understand how they were projected. In order to reach a sack of meal which was well protected below, they broke through the roof of the room in which it was, and built a straight tube from the breach they had made down to the sack. As soon as they tried to carry off their booty to a safe place, they became convinced that it was impossible to pull it up the straight road. In order to meet this difficulty, they adopted the principle of the smooth incline, the use of which we have already seen in the interior of their nests, and built close to the first tube a second, which wound spirally within, like the famous clock tower of Venice. It was now an easy task to carry their booty up this road and so away. . . . Either from the desire to remain undiscovered, or from their liking for darkness, they have the remarkable habit of destroying and gnawing everything from within outwards, and of leaving the outside shell standing, so that from the outside appearance the dangerous state of the inside is not perceptible. If, for instance, they have destroyed a table or other piece of household furniture, in which they always manage from the ground upwards to hit exactly the places on which the feet of the article rest, the table looks perfectly uninjured outside, and people are quite astonished when it breaks down under the slightest pressure. The whole inside is eaten away, and only the thinnest shell is left standing. If fruits are lying on the table, they also are eaten out from the exact spot on which they rest on the surface of the table. . . .

"Hagen also states that they never cut right through the corks which stop up stored bottles of wine, but leave a very thin layer, which is sufficient to prevent the outflow of the wine and the consequent destruction of the workers. The same author relates that in order to reach a box of wax lights they made a covered road from the ground up to the second storey of a house."

It is difficult to realise the constructive skill of the white ants. That myriads of tiny creatures should in the absence of sight be able to work in concert and produce highly complex habitations is very wonderful, but that they should repair their dwellings with such promptitude and to such good purpose implies a high degree of intelligence. Their construction of covered passages and tunnels and what are virtually spiral winding stairs is also very remarkable. If a passage be too steep and too direct, a winding zigzag tunnel is forthwith made. The construction of an ascending spiral passage involves a knowledge of means to ends. It also indicates memory and the power to learn by experience. The enlarging of the royal domain as successive crops of eggs are laid by the queen also bespeaks prescience and the power to provide increased accommodation according to requirement. Lastly, the division of labour between workers and warriors implies an intelligent comprehension of the situation. The workers are the industrious citizens which attend to all the peaceful avocations of the body politic ; the soldiers, larger in size and with formidable mandibles, do all the fighting, but positively refuse to perform any kind of menial labour.

§ 258. Bees and Wasps.

As bees and wasps have a good deal in common it will be convenient to consider them together, especially where they illustrate particular points.

Both differ from ants in having much greater powers of vision.[1] Not only do bees and wasps see for considerable distances, they also distinguish colours. This was proved by Sir John Lubbock (Lord Avebury), who placed honey on slips of paper variously coloured. The bees and wasps which had been allowed to feed on the honey on a particular coloured slip followed the slip when removed to a new position in preference to taking the honey from another coloured slip which was substituted for the original one. The bees and wasps obviously remember colour. It was found that they could distinguish between black, white, yellow, orange, green, blue, and red, and preferred certain colours to others. Thus two or three bees paid twenty-one visits to the orange and yellow, and only four to all the other slips. "The slips were then moved, after which, out of thirty-two visits, twenty-two were to the orange and yellow. Another colour to which a similar preference was shown is blue."

Sir John also showed that bees have a sense of smell. This he determined by sprinkling eau-de-Cologne and other scents at the entrance of a bee-hive. The immediate effect was to cause a number of bees to rush out of the hive to see what was the matter. A repetition of the scenting process produced no result, showing that the bees had taken in the situation and become accustomed to the new conditions.

He failed to make out a sense of hearing. That bees, however, do possess this sense seems proved by the observations of Huber, who has recorded the fact that the queen bee emits certain sounds which have great significance and are duly interpreted. Thus to the piping of a pupa queen she replies in threatening tones. She likewise occasionally strikes terror into all the bees of the hive by making a humming noise, which causes them to remain motionless as if stupefied.

According to De Fravière bees emit from the stigmata of the thorax and abdomen various notes or tones by which they communicate information to each other: "As soon as a bee arrives with important news, it is at once surrounded, emits two or three shrill notes, and taps a comrade with its long, flexible, and very slender feelers, or antennæ. The friend passes the news on in similar fashion, and the intelligence soon traverses the whole hive. If it is of an agreeable kind—if, for instance, it concerns the discovery of a store of sugar or of honey, or of a flowering meadow—all remains orderly. But, on the other hand, great excitement arises if the news presages some threatened danger, or if strange animals are threatening invasion of the hive. It seems that such intelligence is conveyed first to the queen, as the most important person in the state."

When bees and wasps are irritated their familiar buzzing note is raised to a higher pitch. This I have myself noticed on various occasions. The fact that bees and wasps can emit notes varying in pitch goes far to prove that the notes in question are heard by each other and have a significance. If, further, the angry or war note has a higher pitch than the contented or peace note, it follows that the several notes have a meaning.

The sense of direction is well marked both in bees and wasps. The bee-line is a familiar phrase indicating the shortest return route to the hive. There should also be a wasp-line.

Sir John Lubbock experimented with a wasp with the following result. He says: "I marked a wasp, the nest of which was round the corner of the house, so that her direct way home was not out of the window by which she had entered, but in the opposite direction, across the room to a window which was closed. I watched her for some hours, during which time she constantly went to the wrong window, and lost much time in buzzing about at it. For ten consecutive days this wasp paid numerous visits, coming in at the open window, and always trying, though always unsuccessfully, to return to her nest in the 'wasp-line' of the closed window—buzzing about that window for hours at a time, though eventually, on finding it closed, she returned and went round through the open window by which she had entered."

The persistency of the wasp to return to her nest by or through the closed window, the direct route to her nest, was very remarkable. That the insect could not deal with a transparent obstacle was not to be wondered at. It might as well have been asked to deal with an abstract thought. The fact, however, that even after ten days it learned to return to the nest through the open window proved that memory and a reasoning faculty were at work. That insects, and animals far beneath them, are capable of profiting by individual experience and learning goes without saying.

Bees and wasps, while undoubtedly possessing a sense of direction, require to learn their way about. This is shown by their taking short flights from the hives or nests to begin with, and gradually extending them till miles are covered.[2] In the outward journeys the insects fly about in various directions, cover much ground, and take

[1] The lateral eyes and the triple cyclopean eye on the brow of the bee are composed of from 6000 to 7000 facets.
[2] Professor Hugh Blackburn is of opinion that bees extend their flights to ten or more miles. (*Nature*, vol. xii., p. 68.)

numerous bearings which act as signal posts. In the home journey they fly direct, by the so-called bee and wasp lines.

Sir John Lubbock remarks: "I never found bees to return if brought any considerable distance at once. By taking them, however, some twenty yards each time they came to the honey, I at length *trained* them to come to my room." It should be here remarked that if the bees *had not been taken* but left to themselves the probability is they would have managed much better, as they would in this case have taken their own bearings for distances greatly exceeding twenty yards.

If stationary bee-hives be removed during the night, even short distances, the bees, unless trained, return to the localities from which the hives have been removed, and have difficulty in finding the new sites. The old bees experience more difficulty than the young ones, which are more active and adaptive. This seems to prove that memory as well as observation is required in re-finding the hives.

In *movable* hives, the bees accustomed to search for them experience no difficulty. Thus in France certain bee-keepers place the hives on a boat and allow the boat to float slowly down rivers. The bees gather honey and pollen, and return at intervals to the floating hives in the most unconcerned manner. The bees have been taught to look out for the moving hives. This betokens observation, memory, experience, adaptation, and a considerable amount of reasoning power.

Mr. Bates furnishes some remarkable information in this connection on the sand-wasp (*Polistes carnifex*) at Santarem.

He observes that the insects which have their nest in the sand always take several turns in the air before leaving it, to enable them to detect the entrance on their return.

This observation has been confirmed by Mr. Belt. He watched a sand-wasp hunting about for caterpillars, and presented one, about an inch long, to it on the end of a stick, which it immediately seized and bit all over, reducing it to a pulp. "It rolled up about one half of it into a ball, and prepared to carry it off. Being at the time amidst a thick mass of a fine-leaved climbing plant, it proceeded, before flying away, to take note of the place where it was leaving the other half. To do this, it hovered in front of it for a few seconds, then took small circles in front of it, then larger ones round the whole plant. I thought it had gone, but it returned again, and had another look at the opening in the dense foliage down which the other half of the caterpillar lay. It then flew away, but must have left its burden for distribution with its comrades at the nest, for it returned in less than two minutes, and making one circle round the bush, descended to the opening, alighting on a leaf, and ran inside. The green remnant of the caterpillar was lying on another leaf inside, but not connected with the one on which the wasp alighted, so that in running in it missed it. . . . It then flew out again, and the same process was repeated again and again. Always, when in circling round it came in sight of the seed-pods (apparently its mark), down it pounced, alighted near them, and recommenced its quest on foot. I was surprised at its perseverance, and thought it would have given up the search; but not so, it returned at least half-a-dozen times, and seemed to get angry, hurrying about with buzzing wings. At last it stumbled across its prey, seized it eagerly, and as there was nothing more to come back for, flew straight off to its nest, without taking any further note of the locality. Such an action is not the result of blind instinct, but of a thinking mind; and it is wonderful to see an insect so differently constructed using a mental process similar to that of man."

Considerable differences are to be noted in the capacity of bees and wasps. Some are much more clever than others. They have also better memories.

Sir John Lubbock succeeded in taming a sand-wasp, and had it in his possession for nine months. He says: "I had no difficulty in inducing her to feed on my hand; but at first she was shy and nervous. She kept her sting in constant readiness. . . . Gradually she became quite used to me, and when I took her on my hand apparently expected to be fed. She even allowed me to stroke her without any appearance of fear, and for some months I never saw her sting."

Considerable difference of opinion exists as to whether bees are affectionate and sympathetic.

Sir John Lubbock cites experiments to show that they are neither the one nor the other. His information is of a negative character, but against it much information of a positive character may be placed. Thus Réaumur [1] gives a case where a hive-bee was nearly drowned and rendered insensible; her co-workers in the hive carefully licked and tended her till she recovered. Bees, like ants, pay more attention to ailing and injured companions than to healthy individuals in distress.

As regards powers of communication, there can be no doubt that bees and wasps both possess it.

Huber avers that when a wasp finds a store of honey "it returns to its nest, and brings off in a short time a hundred other wasps." Dujardin makes a similar statement regarding bees: "The individual which first found

[1] "Insects," vol. v., p. 265.

a concealed store of honey informed other individuals of the fact, and so on till numberless individuals had found it."

Herr F. Müller narrates a curious example of communication between the queen and the other bees in one of his hives.

The queen had deposited eggs in forty-seven cells situated on two old combs and one new one. When she had finished her task she made several trips round the combs to make sure that the cells were all filled. She somehow overlooked four cells on the new comb, whereupon the worker bees ran impatiently from the new comb to the queen, pushing her, in an odd manner, with their heads, as they did also other workers they met with. "Thus the workers knew how to advise the queen that something was as yet to be done, but not how to show her *where* it had to be done."

Mr. Josiah Emery[1] further observes that the "bee-hunters" of America are not only aware that bees can, and do, communicate with each other, but they take advantage of the fact, and in the following ingenious manner:—

Resorting to fields and woods at safe distances from tame or hive-bees with a box of honey, they capture one or more wild bees, which they duly place in the box and allow them to regale themselves. The wild bees are then liberated, soon to return with others to whom they have confided the secret of the box of honey. These in turn are captured, fed, and liberated. When a sufficient number of wild bees has been secured the hunters separate to a considerable distance, each carrying some of the wild bees. These are liberated at a given signal, and as the bees make straight for their nest, the nest is discovered by a species of triangulation; its position corresponding to the point where the bee-lines converge and meet.

Landois states that if a saucer of honey be placed near a hive a few bees come out and emit a shrill cry of "Tut, tut," whereupon a large number of bees emerge from the hive to enjoy the dainty repast. He adds: "The best way to observe the power of communication possessed by bees by means of their interchange of touches, is to take away the queen from a hive. In a little time, about an hour afterwards, the sad event will be noticed by a small part of the community, and these will stop working and run hastily about over the comb. But this only concerns part of the hive, and the side of a single comb. The excited bees, however, soon leave the little circle in which they at first revolved, and when they meet their comrades they cross their antennæ and lightly touch the others with them. The bees which have received some impression from this touch now become uneasy in their turn, and convey their uneasiness and distress in the same way to the other parts of the dwelling. The disorder increases rapidly, spreads to the other side of the comb, and at last to all the members of the hive."

The antennæ are most important structures in many ways. They assist in communicating, scenting, &c. If bees are deprived of them they are at once reduced to a state of bewilderment, even greater than that witnessed in ants. Huber observes that a queen bee so mutilated ran about in confusion and dropped her eggs at random; she also failed to take with precision the food offered to her. She even tolerated the presence of a similarly mutilated queen placed near her, as likewise did the workers in her vicinity. When an unmutilated queen was introduced the workers at once attacked her.

Huber tested the power of communicating by means of the antennæ by the following remarkable experiment. He divided a hive by a solid partition wall. The half of the hive which had no queen became much excited, the excitement only being allayed when some workers began to build some royal cells. He then divided the hive by means of a porous partition or trellis work. In this case no confusion arose in the half of the hive minus the queen, and no attempt was made to build royal cells. The royal dame could be seen crossing antennæ with the workers on the side opposite to herself, and the order in the hive was perfect.

L. Brofft[2] relates a case where communications must have passed and to good purpose between two hives—a rich and a poor one. The rich hive had lost its queen, and after many civilities and deputations between the contracting parties the rich hive migrated with all its treasures to the poor one, where there was a fertile, vigorous queen, which promised progeny and future greatness.[3]

Mr. Romanes has given an admirable account of the manner in which bees collect their food, make queens, raise

[1] *Nature*, vol. xii., pp. 25, 26.

[2] *Der Zoologische Garten* (18th year, No. 1, p. 67).

[3] Bees, according to M. Maeterlinck, must be able to give expression to thoughts and feelings by means either of a phonetic vocabulary, or, more probably, of some kind of tactile language or magnetic intuition, corresponding perhaps to senses and properties of matter that are wholly unknown to us. And such intuition well might lodge in the mysterious antennæ—containing, in the case of the workers, according to Cheshire's calculation, twelve thousand tactile hairs and five thousand "smell hollows"—wherewith they probe and fathom darkness. For the mutual understanding of the bees is not confined to their habitual labours; the extraordinary also has a name and place in their language, as is proved by the manner in which news good or bad, normal or supernatural, will at once spread in the hive—the loss or return of the mother, for instance, the entrance of an enemy, the intrusion of a strange queen, the approach of a band of marauders, the discovery of treasure, &c.

The brain of the bee, according to the calculations of Dujardin, constitutes the 174th part of the insect's weight, and that of the ant the 269th part. On the other hand, the peduncular parts, whose development usually keeps pace with the triumphs the intellect achieves over instinct, are somewhat less important in the bee than in the ant.

their young, swarm, slaughter drones, and make wax, propolis, &c. As it furnishes an interesting summary of facts I take the liberty of transcribing it: "The food collected consists of two kinds, honey (which although stored in the crop for the purpose of carriage from the flowers to the cells, appears to be but the condensed nectar of flowers) and so-called 'bee-bread.' This consists of the pollen of flowers, which is worked into a kind of paste by the bees and stored in their cells till it is required to serve as food for their larvæ. It is then partly digested by the nurses with honey, so that a sort of chyle is formed. It is observable that in each flight the 'carrier bees' collect only one kind of pollen, so that it is possible for the 'house bees' (which, by the way, are the younger bees, left at home to discharge domestic duties with only a small proportion of older ones, left probably to direct the more inexperienced young) to sort it for storage in different cells. In the result there are several different kinds of bee-bread, some being more stimulating or nutritious than others. The most nutritious has the effect, when given to any female larva, of developing that larva into a queen or fertile female. This fact is well known to the bees, who only feed a small number of larvæ in this manner, and the larvæ which they select so to feed they place in larger or 'royal cells,' with an obvious foreknowledge of the increased dimensions to which the animal will grow under the influence of this food. Only one queen is required for a single hive: but the bees always raise several, so that if any mishap should occur to one, other larvæ may be ready to fall back upon.

"Besides honey and bee-bread, two other substances are found in bee-hives. These are propolis and beeswax. The former is a kind of sticky resin collected for the most part from coniferous trees. This is used as mortar in building, &c. It adheres so strongly to the legs of the bee which has gathered it, that it can only be detached by the help of comrades. For this purpose the loaded bee presents her legs to her fellow-workers, who clean it off with their jaws, and while it is still ductile, apply it round the inside of the hive. According to Huber, who made this observation, the propolis is applied also to the inside of the cells. The workers first planed the surfaces with their mandibles, and one of them then pulled out a thread of propolis from the heap deposited by the carrier bees, severed it by a sudden throwing back of the head, and returned with it to the cell which it had previously been planing. It then laid the thread between the two walls which it had planed; but, proving too long, a portion of the thread was bitten off. The properly measured portion was then forced into the angle of the cell by the fore-feet and mandibles. The thread, now converted into a narrow ribbon, was next found to be too broad. It was therefore gnawed down to the proper width. Other bees then completed the work which this one had begun, till all the walls of the cells were framed with bands of propolis. The object of the propolis here seems to be that of giving strength to the cells.

"The wax is a secretion which proceeds from between the segments of the abdomen. Having ingested a large meal of honey, the bees hang in a thick cluster from the top of their hive in order to secrete the wax. When it begins to exude, the bees, assisted by their companions, rub it off into heaps, and when a sufficient quantity of the material has thus been collected, the work begins of building the cells. The cells are used both for storing food and rearing young.[1]

"All the eggs are laid by one queen, who requires during this season a large amount of nourishment—so much, indeed, that ten or twelve working bees (that is, sterile females) are set apart as her feeders. Leaving the royal cell, she walks over the nursery combs attended by a retinue of workers, and drops a single egg into each open cell.[2]

[1] M. Maeterlinck, speaking of the formation of wax, says: "The greater portion (of the bees), forming in solid columns, like an army obeying a definite order, will proceed to climb the vertical walls of the hive. The cupola reached, the first to arrive grapple it with the claws of their anterior legs, those that follow hang on to the first, and so in succession, until long chains have been formed that serve as a bridge to the crowd that rises and rises. And by slow degrees, these chains, as their number increases, supporting each other and incessantly interweaving, become garlands which, in their turn, the uninterrupted and constant ascension transforms into a thick, triangular curtain, or rather a kind of compact and inverted cone, whose apex attains the summit of the cupola, while its widening base descends to a half, or two-thirds, of the entire height of the hive. And then, the last bee that an inward voice has impelled to form part of this group having added itself to the curtain suspended in darkness, the ascension ceases; all movement slowly dies away in the dome; and, for long hours, this strange inverted cone will wait, in a silence that almost seems awful, in a stillness one might regard as religious, for the mystery of wax to appear. . . . Let us take up a fold of the festooned curtain in whose midst a strange sweat, white as snow and airier than the down of a wing, is beginning to break over the swarm. For the wax that is now being born is not like the wax we know; it is immaculate, it has no weight; seeming truly to be the soul of the honey, that itself is the spirit of the flowers. To follow the various phases of the secretion and employment of wax by a swarm that is beginning to build, is a matter of very great difficulty. All comes to pass in the blackest depths of the crowd whose agglomeration, growing denser and denser, produces the temperature needful for this exudation, which is the privilege of the youngest bees."

Huber was the first to study the formation of wax carefully. "It is not known how the wax is produced from the honey. In making wax the bees will remain suspended from eighteen to twenty-four hours in a temperature so high that one might almost believe that a fire was burning in the hollow of the hive; and then white and transparent scales will appear at the opening of four little pockets that every bee has under its abdomen."

[2] I have watched the process of feeding the queen and her manner of laying the eggs with great interest in a glass hive at Yester House, the residence of the Marquis of Tweeddale. The movements of the queen were dignified and regal in the extreme, and the attentions of her maids of honour of the most courtly and flattering description. The moment she desisted from her egg-laying operations they rushed up on either side of her and presented limpid honey by the aid of their antennæ. Of this dainty repast she partook most graciously, and after a very graceful fashion. She allowed herself very little time either for feeding or resting, and returned to her herculean task in a remarkably short space of time. The task may well be described as herculean when it is remembered that a good hive of bees consists of from 80,000 to 96,000 individuals, and that she is the mother of all. The queen actually lays between two and three thousand eggs each day. Her almost sole function is that of egg-laying. She

"It is a highly remarkable fact that the queen is able to control the sex of the eggs which she lays, and only deposits drone or male eggs in the drone cells, and worker or female eggs in the worker cells—the cells prepared for the reception of drone larvæ being larger than those required for the worker larvæ. Young queens lay more worker eggs than old queens, and when a queen, from increasing age or any other cause, lays too large a proportion of drone eggs, she is expelled from the community or put to death. It is remarkable, also, under these circumstances, that the queen herself seems to know that she has become useless, for she loses her propensity to attack other queens, and so does not run the risk of making the hive virtually queenless. There is now no doubt at all that the determining cause of an egg turning out male or female is that which Dzierzon has shown, namely, the absence or presence of fertilisation—unfertilised eggs always developing into males, and fertilised ones into females. The manner, therefore, in which a queen controls the sex of her eggs must depend on some power that she has of controlling their fertilisation.[1]

"The eggs hatch out into larvæ, which require constant attention from the workers, who feed them with the chyle or bee-bread already mentioned. In three weeks from the time that the egg is deposited, the white worm-like larva has passed through its last metamorphosis. When it has emancipated itself its nurses assemble round it to wash and caress it, as well as to supply it with food. They then clean out the cell which it has left.

"When so large a number of the larvæ hatch out as to overcrowd the hive, it is the function of the queen to lead forth a swarm. Meanwhile several larval queens have been in course of development, and matters are so arranged by the foresight of the bees, that one or more young queens are ready to emerge at a time when otherwise the hive would be left queenless. But the young queen or queens, although perfectly formed, must not escape from their royal prison-houses until the swarm has fairly taken place : the worker bees will even strengthen the coverings of these prison-houses if, owing to bad weather or other causes, swarming is delayed. The prisoner queens, which are fed through a small hole in the roof of their cells, now continually give vent to a plaintive cry, called by the bee-keepers 'piping,' and this is answered by the mother queen. The tones of the piping vary. The reason why the young queens are kept such close prisoners till after the departure of the mother queen with her swarm, is simply that the mother queen would destroy all the younger ones, could she get the chance, by stinging them. The workers, therefore, never allow the old queen to approach the prisons of the younger ones. They establish a guard all round these prisons or royal cells, and beat off the old queen whenever she endeavours to approach. But if the swarming season is over, or anything should prevent a further swarm from being sent out, the worker bees offer no further resistance to the jealousy of the mother queen, but allow her in cold blood to sting to death all the young queens in their nursery prisons. As soon as the old queen leaves with a swarm, the young queens are liberated in succession, but at intervals of a few days ; for if they were all liberated at once they would fall upon and destroy one another. Each young queen as it is liberated goes off with another swarm, and those which remain unliberated are as carefully guarded from the liberated sister queen as they were previously guarded from the mother queen. When the season is too late for swarming the remaining young queens are liberated simultaneously, and are then allowed to fight to the death, the survivor being received as sovereign."[2]

That which the hive seems most to dread is the loss of its queen. This is the crowning calamity, to avert which all the so-called *instincts* and reasoning powers both of workers and queens are directed. "And that these so-called *instincts* are controlled by intelligence is suggested, if not proved, by the adaptations which they show to

never leaves the hive unless on her nuptial flight, and lives for the most part in darkness. Her tenure of life extends to four or five years ; that of the ordinary working bee to six or seven weeks. Her rôle is virtually that of reproduction and continuity. Prior to impregnation a young or virgin queen, like the working or sister bees, can only lay male eggs. After impregnation, she can lay male or female eggs at discretion. A young queen is generally sent out with each swarm or young hive—the hives rarely exceeding three. The queen is considerably larger than the male and the sister or working bees. She is peculiar in many ways. She is provided with enormous ovaries and a special organ, the spermatheca ; as stated, she can, when impregnated, lay male and female eggs at pleasure ; she rules and is the mainspring of the hive—a queenless hive invariably deteriorating and perishing ; she never visits the flowers or makes honey, wax, or propolis ; she never collects pollen ; she takes no part in cell construction or comb-making, and is pampered and petted and maintained in great state for reproductive purposes only. The common mother is the object of bee adoration, and the acknowledged centre of all bee activity. She peoples the hive, and she, or a queen daughter, leads out the young swarms. Where the queen goes every one follows implicitly and gladly. There is no duality of control. Each hive can only boast of one reigning queen. She is as absolute in what she does as the Autocrat of all the Russias.

Dire results follow the death or destruction of a reigning queen. The young bees are no longer cared for ; the comb-makers cease work ; the foragers do not visit the flowers ; the guards abandon their post at the entrance of the hive ; marauders and intruders of all kinds enter the hive ; poverty of a pitiless kind overtakes the hive ; the bees, demented, wander about inside and outside the hive, searching in vain for the queen ; they become demoralised, rapidly diminish in numbers, and ultimately perish from want and despair.

[1] "We know that the virgin queen is not sterile ; but the eggs that she lays will produce only males. It is not till after the impregnation of the nuptial flight that she can produce workers (sisters) and drones (males) at will. The nuptial flight places her permanently in possession, till death, of the spermatozoa torn from her unfortunate lover. These spermatozoa, whose number Dr. Leuckart estimates at twenty-five millions, are preserved alive in a special gland known as the spermatheca, which is situated under the ovaries, at the entrance of the common oviduct. It is imagined that the narrow apertures of the smaller cells, and the manner in which the form of this aperture compels the queen to bend forwards, exercise a certain pressure on the spermatheca, in consequence of which the spermatozoa spring forth and fecundate the egg as it passes. In the large cells this pressure would not take place, and the spermatheca would therefore not open. Others, again, believe that the queen has perfect control over the muscles that open and close the spermatheca on the vagina ; and these muscles are certainly very numerous, complex, and powerful" (Maeterlinck, "The Life of the Bee").

[2] "Intelligence of Animals." (International Scientific Series, 7th edition, 1898.)

special circumstances. Thus, for instance, F. Huber smoked a hive so that the queen and older bees effected their escape, and took up their quarters a short distance away. The bees which remained behind set about constructing three royal cells for the purpose of rearing a new queen. Huber now carried back the old queen and ensconced her in the hive. Immediately the bees set about carrying away all the food from the royal cells, in order to prevent the larvæ contained therein from developing into queens. Again, if a strange queen is presented to a hive already provided with one, the workers do not wait for their own queen to destroy the pretender, but themselves sting or smother her to death. When, on the other hand, a queen is presented to a hive which is without one, the bees adopt her, although it is often necessary for the bee-master to protect her for a day or two in a trellis cage, until her subjects have become acquainted with her. When a hive is queenless, the bees stop all work, become restless, and make a dull complaining noise. This, however, is only the case if there is likewise a total absence of royal pupæ, and of ordinary pupæ under three days of age—that is, the age during which it is possible to rear an ordinary larva into a queen.

"As soon as the queen has been fertilised, and the services of the drones therefore no longer required, the worker bees fall upon their unfortunate and defenceless brothers to kill them, either by direct stinging or by throwing them out of the hive to perish in the cold. The 'drones' cells are then torn down, and any remaining drone eggs or pupæ destroyed. Generally all the drones—which may number more than a thousand—are slaughtered in the course of a single day. Evidently the object of this massacre is that of getting rid of useless mouths."

While the drones or males among bees do no work save that of fertilising the queen, it is otherwise with male wasps, which perform the domestic work of the nest and are fed by the foraging sisters. The drones, in a prosperous, vigorous hive, do not generally number more than four or five hundred. In weak hives the number may be increased to as many thousands. The excess of drones tends to impoverish the hive, as each drone requires five or six working bees to forage and provide it with honey.

In a well-ordered hive, there are one reigning queen, five hundred or more males, and from sixty to eighty thousand sisters or working bees.

Büchner records some remarkable facts bearing on the massacring of the males or drones as they are called. "That the massacre of the drones is not performed entirely from an instinctive impulse, but in full consciousness of the object to be gained, is proved by the circumstance that it is carried out the more completely and mercilessly the more fertile the queen shows herself to be. But in cases where this fertility is subject to serious doubt, or when the queen has been fertilised too late or not at all, and therefore only lays 'drones' eggs, or when the queen is barren, and new queens, to be fertilised later, have to be brought up from working-bee larvæ, then all or some of the drones are left alive, in the clear prevision that their services will be required later. . . . Not less can it be regarded as a prudent calculation of circumstances when the bees of a hive, brought from our temperate climate to a more southern country, where the time of collecting lasts longer, do not kill the drones in August, as usual, but at a later period, suitable to the new conditions."

In the case of wasps the slaughter is of the larvæ and not of the mature insects. As a matter of fact the wasps all perish at the end of the autumn, a few fertilised, pregnant females excepted.

When bees are about to swarm "there is a great excitement and buzzing in the hive, the temperature of which rises from 92° to 104°. Scouts having been previously sent out to explore for suitable quarters wherein to plant the new colony, these now act as guides. The swarm leave the hive with their queen. The bees which remain behind busy themselves in rearing out the pupæ, which, soon arriving at maturity, also quit the hive in successive swarms. According to Büchner, secondary swarms with young queens send out no scouts, but fly at random through the air. They clearly lack the experience and prudence of the older bees."

One of the most remarkable features of bees, as of ants, is their pugnacity. They fight duels, have internecine wars, and attack rival hives in force.

They are also prone to thieving, and carry on their pillage singly, in small numbers, and in the aggregate. The so-called robber-bees know that they are delinquents, and sneak about at the outset, but become hardened, bold, and cruel, as their career in wrong-doing is prolonged. This downward course is eminently human under similar circumstances. "They show by their whole behaviour—creeping into the hive with careful vigilance—that they are perfectly conscious of their bad conduct; whereas the workers belonging to the hive fly in quickly and openly, and in full consciousness of their right. If such solitary burglars are successful in obtaining plunder, their bad example leads other members of their own community to imitate them: thus it is that the whole bee-nation may develop marauding habits, and when they do this they act in concert to rob in force."

Siebold records similar facts regarding wasps (*Polistes gallica*).

§ 259. Intelligence of the Bees, &c.

It would not be safe to deny to the bee, ant, spider, centipede, and other humble forms a considerable degree of intelligence.

While authorities are divided as to the amount of intelligence possessed, all, or nearly all, concede a reasoning principle.

Sir John Lubbock (Lord Avebury), who devoted a large share of attention to bees and performed various experiments with them, credited them with the power of communication, adaptation, and the ability to take advantage of adventitious circumstances. He, however, denied to them the power of extricating themselves from a difficult situation. Thus he put several bees and flies in an open bottle and placed it on its side with the bottom turned towards the window. The flies escaped from the trap in two or three minutes, while the bees remained prisoners, and exhausted themselves in vain endeavours to find a way through the thick illuminated bottom of the bottle. This was scarcely a fair experiment, as bees always make for the light, and the interposition of a transparent glass medium puzzled and threw them off their guard. That the flies so soon escaped shows that the experiment was faulty; it being admitted on all hands that flies are not nearly so intelligent as bees. The American apiarist, Mr. Langstroth, also attributed to the bee a certain degree of stupidity. He says: "As the fly was not intended to banquet on blossoms, but on substances in which it might easily be drowned, it cautiously alights on the edge of any vessel containing liquid food, and easily helps itself, while the poor bee, plunging in headlong, speedily perishes. The sad fate of their unfortunate companions does not in the least deter others who approach the tempting lure, from madly alighting on the bodies of the dying and the dead, to share the same miserable end! No one can understand the extent of their infatuation until he has seen a confectioner's shop assailed by myriads of hungry bees. I have seen thousands strained out from the syrups in which they had perished; thousands more alighting even in the boiling sweets; the floors covered and windows darkened with bees, some crawling, others dying, and others still so completely besmeared as to be able neither to crawl nor to fly—not one bee in ten able to carry home its ill-gotten spoils, and yet the air filled with new hosts of thoughtless comers!" [1]

Here again the contrast between the bee and the fly is to the disadvantage of the former. The conditions are natural to the fly and wholly unnatural to the bee. A fly alights on anything and everything; a bee, for the most part, only on flowers which do not burn or clog the wings. A child, to whom no one will deny intelligence, would have acted pretty much as the bee did. The number of dead bees does not strengthen the indictment against them. Each bee committed a mistake and paid the penalty, and that is all that can be said. Even the highest intelligences frequently commit mistakes. M. Buffon had rather a prejudice against bees, and considered them stupid. Speaking of the hive, he says: "This society, therefore, is no more than a physical assemblage ordained by nature, and independent either of knowledge, or reason, or aim."

As explained further on, he attempted a purely mechanical explanation of the construction of the beautiful hexagonal cells of the double honeycomb.

M. Maeterlinck goes to the opposite extreme. He accords to bees the highest degree of intellect after man.

Messrs. Kirby and Spence joined M. Buffon in decrying the intelligence of bees. They exclaim: "Show us a single case where the pressure of events has inspired them with the idea, for instance, of substituting clay or mortar for wax or propolis (bee glue); show us this, and we will admit their capacity for reasoning."

The demonstration demanded by Kirby and Spence has been given by the bees themselves.

"The naturalist, Mr. Andrew Knight, having covered the back of some diseased trees with a kind of cement made of turpentine and wax, discovered that his bees were entirely renouncing the collection of propolis, and exclusively using this unknown matter, which they had quickly tested and adopted, and found in abundant quantities ready prepared, in the vicinity of their dwelling." In like manner bees adopt and substitute flour for pollen when they can get it and when pollen is scarce. If flour be strewed in the vicinity of the hive and one or two bees placed in it, they quickly discover its resemblance to the dust of the anthers, and not only appropriate it but tell other bees, which do likewise. Bees avail themselves of adventitious wax—the foundation wax supplied to domestic hives. M. Mehring, by a happy induction, concluded "that if bees were supplied with combs that had an artificial waxen foundation, they would be spared the labour of fashioning the wax and constructing the cells, which cost them much honey and the best part of their time. He found that the bees accepted these combs most readily, and adapted them to their requirements." Here was a clear case of appreciating and taking advantage of wholly novel conditions.

M. Maeterlinck enlarges on this subject. He says: "If the apiarist have taken the precaution of surrounding the upper lath of some of the frames (of his hive) with a narrow fillet of wax, the bees will be quick to perceive the advantage this tempting offer presents, and will carefully extract the fillet, using their own wax as solder, and

[1] Maeterlinck, pp. 122, 123

will prolong the comb in accordance with the indicated plan. Similarly—and the case is frequent in modern apiculture—if all the frames of the hive into which the bees have been gathered be covered from top to bottom with leaves of foundation wax, they will not waste time in erecting buildings across or beside them, or in producing useless wax, but, finding that the work is already half finished, they will be satisfied to deepen and lengthen each of the cells designed in the leaf, carefully rectifying these when there is the slightest deviation from the strictest vertical. Proceeding in this fashion, therefore, they will possess in a week a city as luxurious and well-constructed as the one they have quitted : whereas, had they been thrown on their own resources, it would have taken them two or three months to construct so great a profusion of dwellings and storehouses of shining wax. This power of appropriation may well be considered to overstep the limit of instinct." M. Maeterlinck goes further, and makes the following important statement : "Transport our black bee to California or Australia, and her habits completely alter. Finding that summer is perpetual and flowers for ever abundant, she will, after one or two years, be content to live from day to day, and gather only sufficient honey and pollen for the day's consumption ; and her thoughtful observation of these new features triumphing over hereditary experience, she will cease to make provision for the winter. In fact it becomes necessary, in order to stimulate her activity, to deprive her systematically of the fruits of her labour." [1]

Nor does the matter rest here. If sweet syrups are provided by the bee-keeper, the bees eagerly appropriate them, even when flowers are plentiful.

Büchner informs us that in Barbadoes, where sugar refineries abound, the bees entirely forsake the flowers, and form their honey exclusively from sugar. Here is initiation and adaptation of a high order.

In some cases the bee displays remarkable ingenuity in obtaining nectar. Thus, when the calyx of a flower is too long and too slender to admit its body, it perforates the bottom of the calyx and so procures the coveted prize. I have seen examples of this recently. It is a mistake to suppose that bees have no initiative and make no progress. In the wild state many bees are solitary, that is, they have not formed themselves into communities, and stand or fall by their own individual efforts. The idea of strength by combination has not taken possession of them.

In the case of the Panurgi, related to the Dasypoda, the bees dig their own subterranean chamber, build their own cells, and live solitary lives. They, however, share a common entrance, as likewise a common gallery, which winds from the surface of the ground to the several cells.

M. Perez explains that "as far as the work of the cells is concerned, each bee acts as though she were alone ; but all make use of the gallery that conducts to the cells, so that the multitude profit by the labours of one individual, and are spared the time and trouble required for the construction of separate galleries."

The humble bee pursues a solitary life at first. It selects a spot, clears, digs and makes it comfortable. It then builds rude, shapeless cells, some of which it stocks with honey and pollen. It deposits its eggs, feeds the larvæ, and soon is surrounded by a swarm of young active daughters. These improve the original nest and the constitution of the cells. The creature comforts increase and the prosperity of the hive continues ; the young humble bees laying eggs in their turn. The humble bees and their nest disappear in the late autumn and winter, and only a solitary female appears in the spring to begin afresh and found a new colony.

According to M. Maeterlinck (pp. 316, 317) the group of the Meliponitæ, which comprises the tropical Meliponæ and Trigona, are the immediate progenitors of the domestic bee.[2] "Here the organisation is as complete as in our own hives. There is a unique mother, there are sterile workers and males. Certain details even seem better devised. The males, for instance, are not wholly idle ; they secrete wax. The entrance to the hive is more carefully guarded ; it has a door that can be closed when nights are cold, and when these are warm a kind of curtain will admit the air. But the republic is less strong, general life less assured, prosperity more limited, than with our bees ; and whenever these are introduced the Meliponæ tend to disappear before them. . . . In both races the fraternal idea has undergone equal and magnificent development, save in one point alone. . . . In the mechanical organisation of distributed labour, in the precise economy of effort—briefly, in the architecture of the city—they display manifest inferiority."

In gregarian wild bees, especially in mild climates, their nests are found in trees and in natural hollow spaces and crevices ; the hive not being provided with a protective covering. All this is changed when the rigour of the climate demands it, ingenious waterproof hives being constructed. In making their double combs bees construct their cells with hexagonal walls terminating in three-sided, pyramidal, closed portions, which is the most economical as far as material, space, and strength are concerned (see Plate cxlv., p. 926).

In the case of *Apis florea* the cells for the male bees are not hexagonal but cylindrical. This particular bee

[1] "The Life of the Bee," by Maurice Maeterlinck. London, 1901, pp. 311, 312.
[2] Hermann Müller regards the little wild bee, which is found all over the world (Prosopis), as the primitive bee from which all others have descended. The wild bees, it is estimated, amount to over 4000 varieties.

has not fully and finally adopted the hexagonal shape for all its cells. The humble bees also construct roundish, ill-shaped cells.

Domestic bees build four kinds of cells : and these are constructed, not in a haphazard way, but for special purposes and according to design.

(*a*) Royal cells, which are large and somewhat acorn-shaped, for the accommodation of the queens.

(*b*) Large hexagonal cells for the rearing of males and the storing of provisions.

(*c*) Small hexagonal cells for the rearing of sister or working bees, employed also as ordinary store rooms, and occupying about four-fifths of the hive ; and

(*d*) Transition cells to fill up odd spaces, and which are more or less irregular in form. The male and female hexagonal cells are amazingly symmetrical, and as nearly as may be mathematically perfect.

According to Dr. Reid, " there are only three possible figures of the cells which can make them all equal and similar without any useless interstices. These are the equilateral triangle, the square, and the regular hexagon. Of the three figures the hexagon is the most proper for convenience and strength. Bees, as if they knew this, make their cells regular hexagons. Again it has been demonstrated that, by making the bottoms of the cells to consist of three planes meeting in a point, there is a saving of material and labour in no way inconsiderable. The bees, as if acquainted with these principles of solid geometry, follow them most accurately. It is a curious mathematical problem at what precise angle the three planes which compose the bottom of a cell ought to meet, in order to make the greatest possible saving, or the least expense of material and labour. This is one of the problems which belongs to the higher parts of mathematics. The ingenious Maclaurin has determined precisely the angle required, and he found, by the most exact mensuration the subject would admit, that it is the very angle in which the three planes at the bottom of the cell of [the double] honeycomb do actually meet." [1]

As stated, the bees make larger cells for the males and queens. They also provide the latter with a rich nitrogenous food called royal jelly—a secretion supplied by the nurse bees. This jelly was supposed at one time to determine the sex as well as the size of the queens. It is now known that the other bees are also fed with this material in the early or larval stage. There is, however, this difference : the queens are exclusively fed on the jelly, the other bees being weaned after a short time, and fed upon a coarser diet, consisting of honey and pollen. The determination of sex is left to the impregnated queen. She can lay male and female eggs at discretion. She, moreover, places them in their proper cells—a remarkable fact unless she deliberates, thinks, and reasons. Curiously enough, the unimpregnated queen and the sister bees can lay eggs, but only male ones. Impregnation is therefore a fundamental necessity of the hive. Both males and females are necessary to its existence and well-being.

The queen bees produce males or drones for procreative purposes. These, as a rule, do no work. They also produce working, active, sister bees, which perform all the drudgery of the hive. The working bees are the breadwinners, the architects, the lawgivers, and the executioners of the hive. They provide wax, propolis, pollen, and honey ; they plan and build the combs, they police and guard the hive ; they regulate the supply of males and queens, and kill off what are in excess. The construction, management, stocking, and feeding of the hive necessitate concerted action. The bees, from the queen down, have certain functions assigned them. They, however, occasionally vary their occupations. Everything is done in the most methodical and business-like manner. When combs are to be formed, say in an old-fashioned, dome-shaped hive, several workers clamber up the sides and roof until they reach the cupola. Arrived there, they dig their front feet into it. Others follow in regular succession and attach themselves to those already in position, from which they depend in more or less regular vertical festoons. These merge into each other, and increase until they form an inverted cone—a living mass of bees. The secretion of wax is then commenced, and the heat engendered in the mass suffices to give ductility to the comb-forming material. Each bee provides from its ventral surface four tiny cup-shaped supplies. At this juncture one of the bees (the master builder) detaches itself from the mass and affixes its wax to the roof and at once lays the foundation of a cell and a comb. Others follow in rapid succession and do likewise. The wax and the comb are disposed in depending vertical layers, and each comb is double—that is, it consists of a central portion, septum, or midrib with a set of hexagonal cells on either side of it. The hexagonal cells are fashioned by two sets of workers (modellers), one set on either side of the midrib, and the cells, as explained, terminate in three-sided, pyramidal, closed portions. They work so accurately to a general and preconcerted plan that the bases, or three-sided pyramidal closed portions of corresponding and opposite cells invariably fit into and are the counterparts of each other ; each cell resembling its neighbour, and being mathematically accurate, as regards its size, shape, and relative position (Plate cxlv., Figs. 1, 2, 3, 4, 5, and 6, p. 926).

In forming the combs the bees calculate the thickness of the combs ; they also allow sufficient space—half an

[1] Taken from Handcock on "Instinct," p. 18.

inch or so—between the combs to admit of ingress and egress to the inmates of the hive; they also provide short cuts from one comb to another; all which shows deliberation, forethought, and calculation.

If by any chance two combs converge and unduly diminish the space which forms the highway for the bees, one or both combs are immediately deflected and the mistake corrected. If a comb has to be formed in an unusual situation the form of the comb is modified. If it is to be suspended from an awkward projection wax and propolis are furnished to meet the difficulty.

M. Buffon and Mr. Darwin endeavoured to account for the beautiful hexagonal cells by mutual pressure, but pressure is denied, and if exerted it would not explain all the facts of the case. If it partially explained the shape of the bodies of the cells, it certainly would not account for the three-sided, pyramidal bases of the cells, which are mathematically exact in their details. Besides, the cells of the humble bee and some others are not hexagonal. The hexagonal cell is most probably the outcome of the experience of an indefinite number of bees working and toiling through long ages. Nor less wonderful is the stocking of the hive. The provisions made for the continuance of the race are of the most elaborate and complete character. The central figure in the hive is the queen. Her history and actions are replete with interest and instruction. The egg to which she owes her existence is deposited in an ample, specially prepared cell, slightly acorn-shaped; she is fed with royal jelly, attains a large size, and is provided with enormous ovaries capable of stocking and re-stocking the hive; each swarm consisting of from sixty to eighty thousand bees. Her birth produces a profound commotion in the busy commonwealth. From the first she exerts a preponderating influence, which is felt rather than seen, for she does not attempt to govern by force. Her influence lasts only so long as she is laying eggs and is useful to the hive. When she is old and no longer capable of procreating she is dethroned or voluntarily seeks seclusion, and is content to spend the remainder of her days in an obscure corner of the hive, where she is guarded and fed by some of her old maids of honour.

If the hive be deprived of its queen by some unlucky accident, and there are no young queens in the cells and available, the *morale* of the hive is immediately destroyed, and everything connected with it comes to a standstill. The bees cease to collect honey, the combmakers strike work, the nurses forsake and do not feed the larvæ, the bees who keep the hive clean neglect their work, and even the guards who turn off and destroy intruders no longer exercise their important functions. Stagnation and despondency overtake the hive and it perishes miserably. If a young, vigorous, parturient queen makes her appearance at this juncture everything is changed as if by magic. Work in every department of the hive is at once resumed, and it quickly regains its quondam prosperity.

The bees display a strange mixture of affection and indifference well exemplified in their treatment of the males and the queen. They are assiduous in their attentions and tolerant to a degree to both, so long as they are necessary to the well-being of the hive. When they cease to be useful they are neglected, and, as a rule, destroyed. The queen's person is sacred so far as stinging is concerned, and if she is to be destroyed she is surrounded by a cordon of bees and practically suffocated. The same thing happens to a strange queen who obtrudes in the hive. If she be allowed to pass the guards a cordon of working bees surround and imprison her. If the reigning queen be made aware of the strange queen's presence she generally offers battle, in which case the stranger queen is liberated. The stranger queen almost invariably succumbs on such occasions. The queen bee, although the mother of the hive, is cruel in turn, and intolerant of the young queens of her own hive. These she seeks to destroy before or after their birth, and they have to be jealously guarded by the working bees. The young queens are kept in stock, so to speak, in case of accident to the reigning queen, and they, with the males, are destroyed at certain seasons, and when they are no longer required as possible parents.

If by any chance two queens are born at the same time they at once engage in deadly combat. One queen must perish. The survivor, jealous, cruel, and fearful lest her sway should be disputed, makes for the cells containing the immature queens, and would ruthlessly destroy them all. The workers interfere, and guard the unborn queens lest accident should befall the reigning queen. To ensure the continuity of the race there must always be an excess of males and queens, but these are killed off when there is no further need of them as prospective parents. The young queen is an imperfect being until she accomplishes her hymeneal flight and is impregnated. This great event is achieved high up in mid air, whither the males follow her. Her impregnation is the death of the unfortunate male who gains her affections, as she appropriates his entire stock of spermatozoa (some millions in number) and the organ which contains them.

The greatest excitement of the hive is connected with swarming, on which occasion a young queen leads out a young brood of bees and forsakes for ever the old hive, with its stores of honey, pollen, larvæ, combs, &c.[1] As the

[1] When a swarm of bees is leaving the hive "a certain number of workers, it is true, will peacefully go to the fields, as though nothing were happening; will come back, clean the hive, attend to the brood cells, and hold altogether aloof from the general ecstasy. These are the ones that will not accompany the queen; they will remain to guard the old home, feed the nine or ten thousand eggs, the eighteen thousand larvæ, the thirty-six thousand nymphs, and seven or eight royal princesses that to-day shall all be abandoned. Why they have been singled out for this austere duty, by what law, or by whom, it is not in our power to divine."

exodus is fraught with much danger and uncertainty, and time is required to find a new habitat, each bee with a mysterious prescience provides herself with sufficient honey to last five or six days. This is necessary, as they are too much excited to search for food so long as the swarming process lasts. During the swarming the bees are amiable to a degree, and seldom or never use their stings even when roughly treated. On such occasions they may be taken up by handfuls and placed in a new empty hive. All the bees follow the lead of the queen. If she be secured the success of a new hive is assured. It is amazing how quickly the new hive, under favourable circumstances, calms down and sets to work. Within a day or two all the young bees of the swarm assume their respective functions; some secrete wax and lay the foundations of combs, others scour the country for propolis, nectar, and pollen; and within quite a short period a new city with its dwellings, its stores, its police, its scavengers, and its guards is produced. As soon as the combs are formed the queen begins her arduous labour as egg-layer for the hive, and a prospective swarm gradually but quickly makes its appearance. A swarm in a strong hive numbers from sixty to eighty thousand individuals; these consisting of fifty or sixty queens, three hundred or four hundred males, and the rest sterile females or workers.

The demand of the queen for cells when once she has fairly assumed her egg-laying function is excessive and practically insatiable. Day and night she works. She receives the homage of every member of the hive. All bow before her and treat her with the utmost deference and courtesy. They even retire from her presence in a backward direction and keep their faces towards her as in human royal courts. She never feeds herself. When she desists from her egg-laying labours for a short interval, attendants (maids of honour) rush up on either side and caress and feed her with the choicest honey. This I have myself seen in transparent glass hives. The fecundity of the queen bee is enormous when tested by the nigh incalculable numbers which go to form a swarm.

The management of the hive is scarcely less remarkable than the stocking of it. The legions forming the hive are to be governed; watch and ward has to be kept over the honey, pollen, and other food stuffs; the larvæ or immature bees are to be fed and cared for; the hive is to be kept clean and guarded; invaders turned out or destroyed; the number of males and queens is to be regulated; combs and new cells are to be formed; the hive is to be ventilated, and heat supplied when wax is to be melted, &c., &c. This means supervision, forethought, law, and order within the hive. It means a systematic and extensive division of labour. Everything in the hive has a use, and the working bees must discharge dissimilar but combined functions. They must all work in concert to given ends.

Lastly, the inmates of the hive, whether larvæ or adults, must be fed. Hunger is imperative and inexorable. Not only must food be forthcoming in the glad summer, when flowers are plentiful and the bees active, but also in the chill winter and spring, when flowers are dead and the bees numb. All this bespeaks design, discipline, and organising power not inferior to that seen in human communities.

The feeding arrangements of bees are miraculous in a way. They toil incessantly from "early morn to dewy eve." For miles around the hive every nectar-yielding flower is visited and robbed of its treasure, whether honey or pollen. Each bee is an independent worker. It zigzags across the meadow or heath in search of particular flowers, or flies into the high lime or other sweet-scented, blossoming trees and shrubs. It meanders round about in a mysterious way, always receding from the hive. When it has secured its load its wandering flight is suddenly checked. The bee steadies itself for a few seconds and then with marvellous precision, as if flying by the aid of a compass, it makes straight for the hive, following the shortest route—the so-called bee line. It may make a hundred journeys in a day to and from the hive, but they are all performed in the same way; namely, a devious outgoing and a straight home-coming. The industry of the bee is proverbial. It is ever on the wing, and works less for itself than for the hive, and the common good. The food collectors and carriers, for the time, busy themselves exclusively with the work assigned them. The storing of the food, the making of cells, the nursing, the cleaning and guarding of the hive, and other functions connected therewith, are entrusted to other workers equally willing and fit to discharge the duties allocated to them by the deliberative body, and with their own approval and consent. All is harmony without and within the hive. The interior of the hive, while a perfect babel to the uninitiated, is, nevertheless, a model of law and order. Each set of workers discharges its own peculiar functions and obligations. There are no misunderstandings, mistakes, or playing at cross purposes. The hive, as a hive, is complete as to its general plan, and all the details and daily routine are carried out with punctuality and precision. Not only is the regular working of the hive provided for, but arrangements are made for possible and occasional breakdowns, as from death or want. This is seen in the prevision which insists on an excess of male and queen bees in the hive to guard against accident to the reigning queen. In the event of her death a young queen and at least one male must be forthcoming, and at comparatively short notice: the queens and males are kept in stock. It is also seen by the prevision which impels the bees to store up honey in the summer for the rigours and want of winter and early spring.

While bees, for the most part, perform certain prescribed duties, they are, on occasion, quite equal to the performance of others. Thus M. Maeterlinck observes: "I often have marked bees that went foraging in the morning, and found that, in the afternoon, unless flowers were especially abundant, they would be engaged in heating and fanning the brood-cells, or perhaps would form part of the mysterious, motionless curtain in whose midst the wax-makers and sculptors would be at work. Similarly I have noticed that workers, whom I have seen gathering pollen for the whole of one day, will bring no pollen back on the morrow, but will concern themselves exclusively with the search for nectar; and *vice versâ*." The division of labour in a hive in full work is carried to an extreme. "It regulates the workers' duties with due regard to their age; it allots their task to the nurses who tend the nymphs and the larvæ, the ladies of honour who wait on the queen, and never allow her out of their sight; the house bees who air, refresh, or heat the hive by fanning their wings, and hasten the evaporation of the honey that may be too highly charged with water; the architects, masons, wax-workers, and sculptors who form the chain and construct the combs; the foragers who sally forth to the flowers in search of nectar that turns into honey, of the pollen that feeds the nymphs and the larvæ, the propolis that welds and strengthens the buildings of the city, or the water and salt required by the youth of the nation. Orders have gone forth to the chemists, who ensure the preservation of the honey by letting a drop of formic acid fall in from the end of their sting; to the capsule-makers, who seal down the cells when the treasure is ripe; to the sweepers, who maintain public places and streets most irreproachably clean; to the bearers, whose duty it is to remove the corpses; and to the amazons of the guard, who keep watch on the threshold by day and by night, question comers and goers, recognise the novices who return from their very first flight, scare away vagabonds and loiterers, expel all intruders, attack redoubtable foes in a body, and, if need be, barricade the entrance."

The bees never mix up the various coloured pollens. Each kind of pollen is kept separate. The various pollens are selected and stored away according to their species and colour. A chief occupation of the hive is the methodical arrangement of the several kinds of pollen. The bees which gather nectar one day will the next gather pollen. This arrangement brings all their organs into play. According to M. de Layens, "the bees would seem to be perfectly informed as to the locality, the relative melliferous value, and the distance of every melliferous plant within a certain radius of the hive. In this fashion, they regulate, day by day, their distribution over the plants, so as to collect the greatest value of saccharine liquid in the least possible time. It may fairly be claimed, therefore, for the colony of bees, that, in its harvesting labours no less than in its internal economy, it is able to establish a rational distribution of the number of workers without ever disturbing the principle of the division of labour.

"The honey of April is the finest, and is stowed away in 20,000 cells against the day of distress. The varied coloured pollen is stowed away in transparent cells; still lower the honey of May matures, in great open vats by whose sides watchful cohorts maintain an incessant current of air. In the centre, and far from the light in the warmest part of the hive, is the royal domain of the brood-cells, set apart for the queen and her acolytes; about 10,000 cells wherein the eggs repose, 15,000 or 16,000 chambers tenanted by the larvæ, 40,000 inhabited by white nymphs to whom thousands of nurses minister. And finally, in the holy of holies of these parts, are the three, four, six, or twelve sealed palaces, vast in size compared with the others, where the adolescent princesses lie who wait their hour, wrapped in a kind of shroud, all of them motionless and pale, and fed in the darkness."

The interior of the hive displays the most extraordinary activity and order. When combs are being formed the bodies of the workers provide the wax and the heat necessary for the manufacture of the cells, which, as a rule, are of the most exquisite hexagonal shapes. The wax first appears as parallel vertical plates depending from the roof of the hive, and these are modelled from either side by two sets of bees into two sets of cells. The dual modelling is performed with extreme exactitude and on mathematical principles. The marvel is that the two sets of modellers can co-ordinate their movements so exactly as to produce such perfect results. The combs, composed of two sets of hexagonal cells, are separated from each other by about half an inch, sufficient space to allow the bees to pass between them, and if by any chance two combs come too close together, one or both combs are deflected and the error corrected. The bees, it will be seen, fix the plates of wax, the foundations of the combs, to the roof of the hive; they leave sufficient space to develop two sets of cells on each plate; they also leave space for free ingress and egress between the combs when completed; they also provide cross avenues, all which argues constructive skill and adaptation of means to ends of no mean order. The construction of the combs and the hive, as a whole, necessitates processes of reasoning. The element of chance finds no place in the architecture of the bees. The hive is to be kept at a certain temperature. This they accomplish by the fanning of their wings. If a comb is to be formed in an unusual situation, the shape of the comb is modified. If it is to be suspended from an awkward projection the means are forthcoming.

On the whole the most outstanding peculiarity of bees is their architecture. This in the case of domestic bees is truly marvellous, and, hitherto, no perfectly satisfactory explanation of it has been given. It has been customary

to refer it to instinct, a term which in the present day and in this connection has no precise or definite meaning, and can only mislead. Bee architecture can only be explained in one of two ways : (*a*) by the interposition of a First Cause working intelligently in and through the bees, or (*b*) the bees themselves have acquired the art of building by experience and reason cumulating through the ages.

CONSTRUCTION OF THE DOUBLE HONEYCOMB OF THE DOMESTIC BEE (*APIS MELLIFICA*)—EVIDENCE OF DESIGN IN SAID CONSTRUCTION

The double honeycomb is so remarkable that I deem it worthy of separate and detailed description and of careful original illustration (Plate cxlv., p. 926). It displays, in my opinion, unmistakable evidence of design, not in one but in several directions. The following points are to be noted :—

1. It is formed from a peculiar secretion (wax) which the honey bee produces from its own body. The spider, another deft designer and worker, supplies the thread from which it spins its wonderful web. The bee, the spider, the ant, certain fishes, and the majority of birds display great constructive skill.

2. If thin sheets of wax are given to bees they cease to secrete, wholly or in part, their own wax, and become designers and builders pure and simple.

3. The double honeycomb is one of the greatest constructive architectural feats in the world, inasmuch as it absolutely secures the greatest amount of strength and accommodation with the least possible material. No piece of mechanism ever devised is better adapted to its peculiar purpose.

4. The double honeycomb and the septum or partition which separates its two halves are constructed on mathematical principles, and even involve a knowledge of the higher mathematics. As the bee cannot be credited with an acquaintance with Euclid, the only explanation that can be given is that the First Cause works in and through the bee, or has conferred on it the necessary intellectual and reasoning powers

5. The bodies of bees are round, and one would naturally have supposed that these ingenious insects would have made the cells of the double honeycomb cylindrical with slightly rounded or flattened ends, and that the ends or basal closed portions of the cells which form the septum or partition between the two halves of the comb would have consisted of two thicknesses. Not so ; a wholly different arrangement obtains. The cells of the two halves of the double honeycomb are not round but *hexagonal or six-sided.* More wonderful still, the basal or closed portions of the cells which form the septum, and consist of alternate prominences and depressions, are not six-sided prominences and depressions but *three-sided only.* This is an astounding modification, and it is here, more especially, that resort is had to the higher mathematics. The septum or partition which divides the two halves of the comb is one of the most remarkable structures known. It consists of the three-sided pyramidal, terminal, or basal portion of one cell wedged into and between three facets supplied by the pyramidal basal portions of three other cells ; the facets of the three cells forming a three-sided pyramidal depression strengthened towards the centre in three directions. The septum is of the same thickness as the walls of the hexagonal cells themselves ; a circumstance of great importance as showing design of a high order. What holds true of the septum is also true of the hexagonal walls of the cells. These are common to neighbouring cells, and consist not of two thicknesses but one ; an arrangement which gives the greatest amount of accommodation and strength with the least possible material.

The septum on section of the double comb in the direction of the length of the cells presents a zigzag appearance, due to the alternate projections and depressions formed by the basal portions of the cells ; a disposition of parts which adds strength and prevents the lateral slipping of the two halves of the comb upon each other. The zigzag appearance referred to, as well as the hexagonal shapes of the cells, the pyramidal, three-sided nature of their terminal or closed portions, and other peculiarities of the double comb, are seen at Plate cxlv., p. 926.

6. The septum is added to at the angles formed by the junctions of the pyramidal basal portions of the cells in such a way as efficiently to secure additional strength without much increase of material ; a matter of considerable interest as affording fresh evidence of design. The pyramidal basal portions of the two sets of cells forming the double honeycomb interdigitate and dovetail into each other ; the apex of each cell being supported by the converging walls and junctions of three other cells ; the walls buttressing and strengthening the apex in all directions. The walls come directly opposite what is to be regarded as the keystone of the arch formed by the pyramidal portions of the cells (Plate cxlv., p. 926).

7. The cells of the double honeycomb are open at the exterior or outer surface of the comb while the queen bee is depositing her eggs and while the larvæ and young bees are being fed. The mouths of the cells are hermetically sealed when the cells are charged with honey, and that precious material is to be safely stored for the winter and spring food. Here, again, there are evidences of design.

8. The cells of the double honeycomb are of various sizes; thus the cells for the accommodation of young queen bees are considerably larger than those of the male bees and the female or working bees, the cells of the former being larger than those of the latter. Not only so; the young queen bees are fed with a peculiarly rich food, which makes them larger and stronger than ordinary bees. Further, the working bees deliberately destroy the young queen bees and males at intervals when they are not required for the well-being and economy of the hive. All this speaks strongly of design and means to ends.

9. The bees under certain circumstances alter the size and shape of the double combs, and thus show not only great constructive power but great adaptive power. In other words, the bees are not rigorously tied down in matters of detail. The power to adjust and adapt indicates a reasoning faculty of no mean order. Either the bees reason, or the Creator who fashioned them, as already indicated, works in and through them. It is worse than useless to refer the power of adaptation to instinct; a term which never had, and never can have, a precise meaning, and is a mere cloak for ignorance.

10. The manner in which the hexagonal cells of the double honeycomb are produced is at once striking and instructive. The bees arrange themselves head to head. They begin with the septum or dividing and most intricate portion of the comb. One bee makes a start on one side of the septum, and slowly but surely produces the three-sided, pyramidal, projecting, closed portion of a cell. While thus engaged, three other bees appear on the opposite side of the septum and, so to speak, work round that portion of the septum which is being formed by the first bee. Each of the three bees in turn produces the three-sided, pyramidal, projecting, closed portion of three other cells; the three sides or faces nearest the original construction forming a triangular depression into which the original pyramidal construction accurately fits. On the one side of the septum is found a series of triangular projections: on the other side a series of triangular depressions. These occur at regular intervals, and fit and dove-tail into each other with extreme accuracy. While one cell terminates in a pyramidal *projecting* portion, no fewer than three other cells take part in the formation of the triangular *depression* or socket into which it fits.

When the three-sided, pyramidal, basal, closed portions of the cells are formed, a most extraordinary modification is witnessed in the walls of the cells themselves. The walls of the cells are constructed not with three sides but with six sides. They form true hexagons. How and why the bees begin with three-sided pyramidal structures and suddenly alter their plan and make the bodies of the cells six-sided passes the comprehension of man, and can only be explained by design and the operation of a First Cause working in and through the bees directly or indirectly, as already stated. The change in design is absolutely necessary according to the requirements of mathematics, and the principle of least action, the saving of material, the securing of the greatest amount of accommodation, and the greatest possible strength. These various advantages could scarcely have been foreseen by the bees, and it is, on the whole, more reasonable to refer the construction of the double honeycomb to the great Designer and Upholder of the universe than to the bees themselves. The bees are rather to be regarded as the instruments which carry out the Divine behests. Similar remarks are to be made regarding the complicated nest of the ant, the dainty, delicate spider's web, the nests of certain fishes, and the nests of birds, so elaborate, varied, and beautiful.

The bees, as will be seen, in constructing the double honeycomb begin with the septum or partition of the comb, and work away from it in the direction of the mouths of the cells. Into the building of the double honeycomb no element of chance enters. Everything is designed. The bees arrange themselves in groups at a certain time, in a given order, and at measured distances. They work in relays simultaneously and together. They are never in each other's way, and each produces its quota of work independently, yet conjointly. They work according to a given plan as certainly as if they were employing compasses, measuring lines, straight edges, plummets, and all the paraphernalia of modern architecture.

M. Buffon, as already indicated, endeavoured to explain the formation of the hexagonal cells of the double honeycomb by mechanical pressure, and strove to establish his theory by soaking, boiling, and swelling peas and beans in a confined space. I have repeated his experiments, and find that the indentation of the peas, beans, &c., by pressure is not necessarily six-sided. The experiments, moreover, altogether fail to explain the fact that the cells of the bee are three-sided at their basal terminal portions in the septum, and six-sided or hexagonal in the bodies of the cells; neither do they explain why some cells are larger than others—how the cells are open when they contain grubs or young bees which are being fed, and closed when they contain honey to tide over the cold winter and early spring.

It should be stated in this connection, that hexagonal formations are not confined to bees. They occur in the inorganic and organic kingdoms not infrequently. In the inorganic kingdom the hexagons, which are solid, are mainly due to shrinkage, as in the basaltic columns of Staffa in Scotland, and the Giant's Causeway in Ireland.[1]

[1] The basaltic columns in question, while mainly six-sided, are occasionally four-sided, five-sided, and seven-sided (see Figs. 1 and 2 of Plate xl., p. 63).

In the organic kingdom the hexagons, which are sometimes solid and sometimes hollow, are in many cases largely due to growth and pressure external or internal. In the production of the hexagonal cells of the double honeycomb there is, however, neither shrinkage nor swelling and pressure in the ordinary sense. The walls of the cells are built by two opposite sets of workers, and there is no reason to suppose that any pressure is exerted save that necessary for the moulding of the plastic wax itself. The walls of the cells are built by neighbouring bees, and the most that can be said is, that the bees engaged on opposite sides of the walls maintain an equilibrium and balance in construction to prevent the bulging of the walls. The question of the hexagonal shape of the cells, and the pyramidal nature of the terminal or closed portions of the cells, is not answered or set at rest by the theory of mechanical pressure.

11. There was no need for a double honeycomb composed of hexagonal cells terminating in pyramidal projections and depressions and a well-defined, complex septum or dividing portion. The humble bee builds isolated or grouped cells, and the cells are rounded and irregular. It is in the construction of the hexagonal cells that design and the reasoning faculty—whether in the Creator or the bee—comes into prominence. The economy of the beehive and the necessities of the honey-bee demand that there shall be no waste of wax, and that the utmost amount of cell accommodation shall be provided in the least possible space, and, in such a way as to give the greatest conceivable degree of strength. These three requirements can only be provided by the double honeycomb, consisting of hexagonal cells terminating in pyramidal closed portions and a septum or dividing partition as described.

12. The double honeycombs are, for the most part, placed vertically or on edge; occasionally they are placed obliquely and even horizontally. The combs are separated from each other by considerable intervals, so as to afford the bees, going to and from the combs, a passage or roadway. Transverse and oblique passages are also provided to enable the bees to pass from one comb to another, all which indicates design and a well-considered plan of construction. Analogous arrangements obtain in the nest of the ant, which may also be regarded as an architectural wonder. Reason of a kind can certainly be detected both in the hive and in the ant's nest. The remarks made on the structure of the double honeycomb, which in my opinion affords striking evidences of design, form but a small contribution to the numerous examples of *means to ends* which a hive in full working order reveals.

The construction of the double honeycomb is very fully illustrated at Plate cxlv.

PLATE CXLV

Plate cxlv. shows the construction of the double honeycomb of the domestic bee (*Apis mellifica*) as witnessed in nature, and depicted by dissections and photographs specially prepared by the Author.

FIG. 1.—Virgin double honeycomb, natural size, placed for convenience in a horizontal position. Shows longitudinal and transverse sections of the comb when full of honey.

At *a*, the external surface of the comb and the hexagonal ends of the hexagonal cells (in this case closed to protect the honey) are seen. The surface of the comb forms a hexagonal mosaic very regular and symmetrical as to its component parts.

At *b* (transverse section of comb a little above the septum or dividing portion), the three-sided pyramidal depressions forming the terminal or closed portions of the hexagonal cells are observed. Between the three sided pyramidal depressions are a corresponding number of three-sided pyramidal elevations; the depressions and elevations dovetailing into each other and forming the septum, or dividing wall between the two halves of the comb. While portions of three different hexagonal cells are required to produce the three-sided pyramidal depressions, portions of only one hexagonal cell are required to produce the three-sided pyramidal elevations. Each pyramidal depression consists of three triangular faces or facets uniting in the middle. The triangular facets are composed of the terminal triangular portions of three different hexagonal cells, and find their counterparts in similar facets occurring on the terminal pyramidal portion of the single hexagonal cell to which reference has been made. It is a remarkable circumstance that the hexagonal or *six-sided* cells should terminate in *three-sided*, pyramidal, closed portions in the centre. This is one of the marvels of the double honeycomb.

At *c* (longitudinal section of comb) the septum or partition which separates the two halves of the comb from each other is seen. The septum is composed of the three-sided, pyramidal, closed portions of two sets of hexagonal cells; the closed portions appearing alternately as depressions and elevations as explained. The septum or longitudinal section, as a consequence, presents a zigzag outline, the closed portions of the hexagonal cells fitting into each other, tenon-mortise fashion. The angles formed by the pyramidal closed portions of the hexagonal cells are strengthened by the deposit of a little additional wax, which gives additional strength with very little additional weight. The septum of the double honeycomb is the most complicated part of the comb and the most difficult to understand.

FIG. 2.—Shows the triangular pyramidal depressions forming part of the septum of the double honeycomb seen at *b*, Fig. 1, and at Fig. 4, greatly enlarged. The triangular depressions, it will be noticed, are each bounded by a solid hexagonal outline; the outlines in question forming the bases of the hexagonal cells. The bases of the hexagonal cells undergo a most remarkable modification, inasmuch as their *six-sided* walls (*vide* solid lines) are suddenly converted into *three-sided* pyramids (*vide* dotted lines); the pyramids forming the terminal closed portions of the hexagonal cells.

This figure also shows the alternate pyramidal elevations and depressions produced by the terminal portions of the hexagonal cells. The pyramidal elevations are seen in any of the three solid lines which converge in the centre of the spaces bounded by the hexagonal dotted lines; the pyramidal depressions are seen in any of the three dotted lines which converge in the spaces bounded by the hexagonal solid lines.

The terminal, pyramidal, closed portions of the hexagonal cells are produced by converting the six walls of each cell into three—

PLATE CXLV

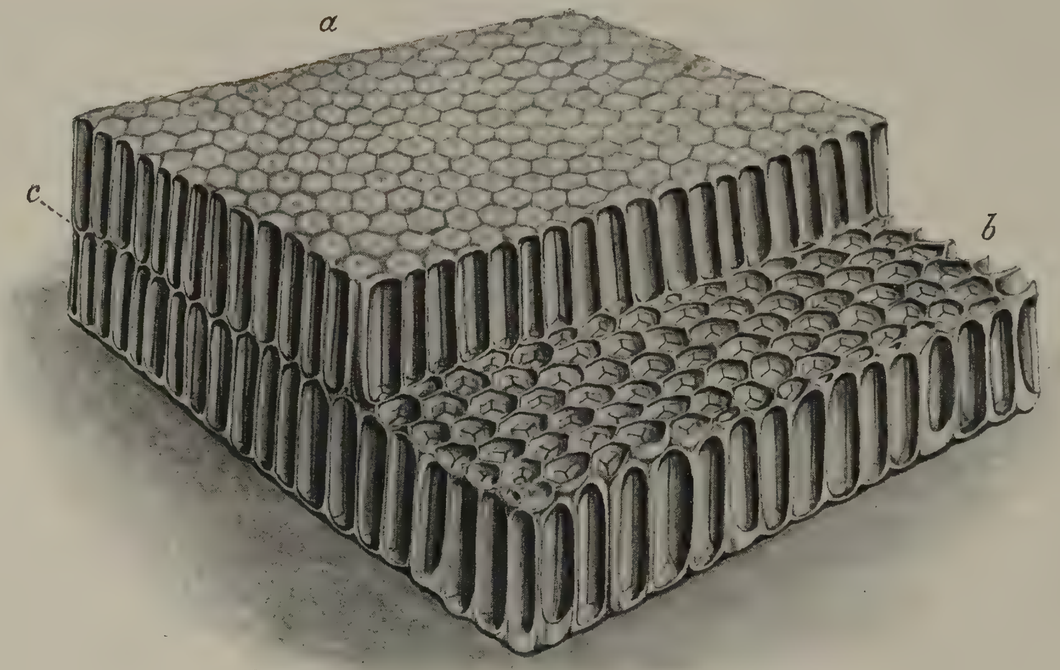


Fig. 1.

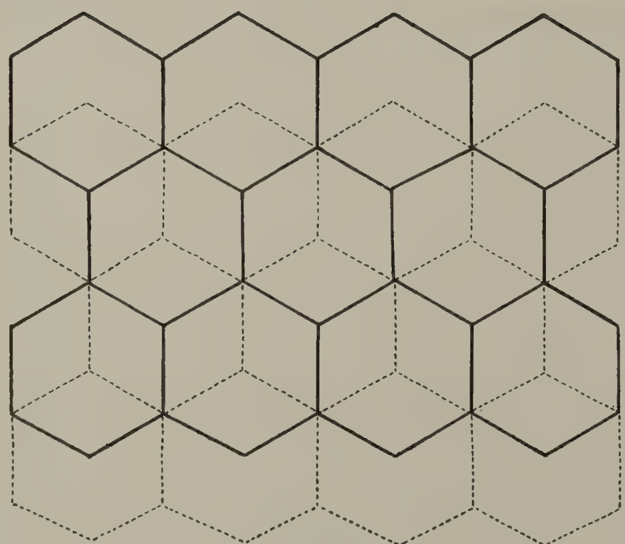


Fig. 2.

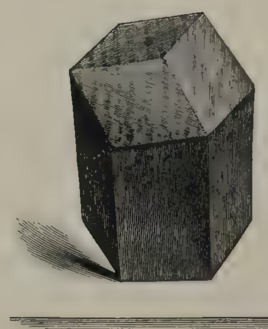


Fig. 4.

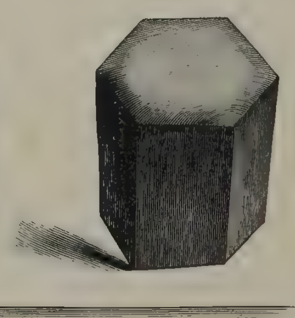


Fig. 5.

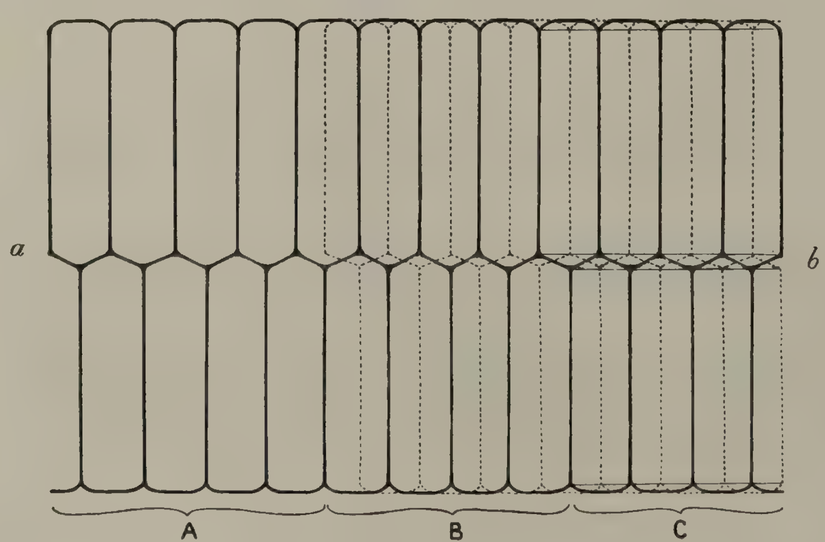


Fig. 3.

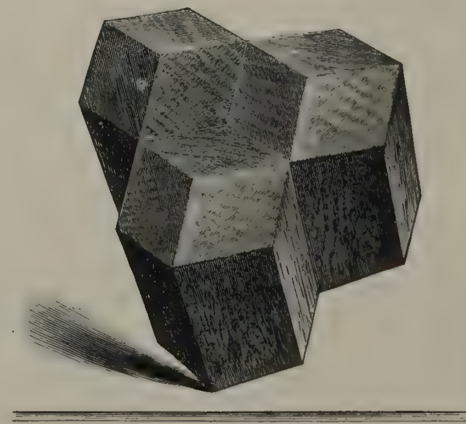


Fig. 6.

PLATE CXLV (*continued*)

the three walls being made to converge and form a pyramid; the pyramids, as explained, interdigitate and fit into each other in the septum or dividing partition of the comb and present on longitudinal section a zigzag outline.

Fig. 3.—Section of the double honeycomb considerably enlarged. Shows how the mouths of the hexagonal cells forming the exterior of the comb are closed when the comb is full of honey, and how the septum or dividing partition of the comb is produced. The mouths of the hexagonal cells are closed by thin hexagonal films of wax slightly rounded and with a depressed centre. The septum (a, b of figure) consists of two sets of hexagonal cells terminating in three-sided, pyramidal, closed portions, which alternate and interdigitate or dovetail to present a zigzag outline.

At A, two sets of hexagonal cells are seen interdigitating in the septum (a, b); the pyramidal closed portions of the cells being alternately directed downwards and upwards.

At B, other two sets of cells are seen looming up behind them (*vide* dotted lines).

At C, the spaces taken up by the closing of the free ends of the hexagonal cells, and the interdigitation of the pyramidal closed portions in the septum or dividing partition of the comb, are indicated.

Fig. 4.—Represents a model of a hexagonal cell terminating in a pyramidal closed portion. The manner in which the six sides of the cell are converted into a three-sided, triangular pyramid is well shown. The pyramidal closed portion of this cell fits into a triangular depression formed by pyramidal portions of three other cells in the septum or dividing portion of the comb as shown in model, Fig. 6. The septum, as explained, consists of the pyramidal closed portions of the two sets of hexagonal cells forming the double comb interdigitating and dovetailing into each other.

Fig. 5.—Represents a model of a hexagonal cell with its mouth closed by a rounded film of wax, as happens when the cell is full of honey.

Fig. 6.—Shows a model of a group of three hexagonal cells each terminating in a three-sided, pyramidal, closed portion. A third part of the terminal, pyramidal, closed portion of each of the three cells referred to unites to form a triangular *depression* into which the triangular *projection* of the hexagonal cell shown in Fig. 4 accurately fits. It is in this way that the zigzag outline of the septum seen on section of the double comb is produced (the Author).

M. Buffon, as already pointed out, attempted a mechanical explanation of the structure of the double honeycomb, and referred its exquisitely beautiful hexagonal cells, with their three-sided prismatic bases, to mechanical pressure. He said if peas and beans be placed in water in a limited space and boiled, they will swell and indent each other, and so assume hexagonal forms and exhibit prismatic bases. His words are: "If you fill a dish with peas or any other cylindrical bean, pour as much water into it as the space between the beans will allow, close it carefully and then boil the water, you will find that all these cylinders have become six-sided columns. And the reason is evident, being indeed purely mechanical: each of the cylindrical beans tends, as it swells, to occupy the utmost possible space within a given area; wherefore it follows that the reciprocal compression compels them all to become hexagonal. Similarly each bee seeks to occupy the utmost possible space within a given space, with the necessary result that, its body being cylindrical, the cells become hexagonal for the same reason as before, namely, the working of reciprocal obstacles." "We might," M. Maeterlinck observes, "reply first of all with Brougham, Kirby and Spence, and others, that experiments with peas and soap-bubbles prove nothing; for the reason that in both cases the pressure produces only irregular forms, and in no wise explains the existence of the prismatic base of the cells. But above all we might answer that there are more ways than one of dealing with rigid necessity: that the wasp, the humble-bee, the Trigonæ and Meliponæ of Mexico and Brazil, achieve very different and manifestly inferior results, although the circumstances, and their own intentions, are absolutely identical with those of the bees. It might further be urged that if the bee's cell does indeed follow the law which governs crystals, snow, and soap-bubbles, as well as Buffon's boiled peas, it also, through its general symmetry, disposition in opposite layers, and angle of inclination, obeys many other laws that are not to be found in matter."

It should be added that M. Maeterlinck performed an experiment where the supposed element of pressure could not possibly be exercised. He removed a considerable number (thirty or thereby) of the hexagonal cells forming one half of a double comb, leaving the septum of the comb intact. He then inserted a tin plate into the bottom of the excavation next the septum, so as to prevent even the semblance of pressure from the opposite side of the septum, provided that were possible. The bees, when pressed for cells, deliberately began to repair the breach, and produced new cells in it. They tinkered the bottom of the cavity and securely fixed the rigid tin plate. Only three bees could work in the excavation at the same time. Notwithstanding this, the entire surface of the unyielding tin plate was in forty-eight hours covered with outlined cells. No mutual pressure could, under the circumstances, occur in the outlining. Symmetrical hexagonal cells were, in due course, erected on the outlined foundations. As only three bees could work in the cavity in question, not more than two of the six surfaces of each cell could, by any possibility, be accounted for by pressure in any form. Four of the surfaces in each hexagonal cell had therefore no *raison d'être* in the reciprocal pressure, obstructive, mechanical theory.

M. Maeterlinck thus sums up: "These cells were less regular, certainly, than those of an ordinary comb. Each cell, however, was a perfect hexagon; nor did it contain a single crooked line, a single curved figure or angle. And

yet the ordinary conditions had all been changed; the cells had neither been scooped out of the block, according to Huber's description, nor had they been designed on a waxen hood, and from being circular at first been subsequently converted into hexagons by the pressure of adjoining cells, as explained by Darwin, neither could there be a question here of reciprocal obstacles, the walls having been formed one by one, and their first lines traced on what was practically a bare table. It would seem incontestable, therefore, that the hexagon is not merely the result of mechanical necessities, but that it has its true place in the plans, the experience, the intellect and will of the bee."

As already explained, I have performed the pea-experiment, and find it is in no way satisfactory or conclusive. The hexagonal forms and prismatic bases obtained by Buffon's experiment are imperfect and irregular to a degree, and have few of the characteristics of the actual bee-cells. The experiment does not furnish the necessary details; it does not explain why the hexagonal cells of a honeycomb are arranged in a double row back to back; why the cells are equidistant and symmetrical; why their prismatic bases are mathematically accurate; why some cells are larger than others and slightly different in construction, as happens in the store cells, the male cells, and those of queen bees.

The argument of pressure on a superficial examination has much to recommend it. It, however, breaks down when carefully looked into. Hexagonal, pentagonal, and other forms are undoubtedly produced by pressure in living, growing structures. Thus in ordinary cell growth, cells which are originally round assume, when they develop in a confined space or under pressure, various shapes. The epithelial cells of the skin, for example, become flattened and slightly indented at the edges; the liver cells and *acini* present a pentagonal outline; and the pigment cells of the choroid coat of the eye show a hexagonal outline (Plate iv., Figs. 11, 12, and 13, p. 7). These several shapes are also produced apart from life and development. Thus at Staffa in Scotland, and the Giant's Causeway in Ireland, there are *hexagonal*-shaped, basaltic columns of rock which very greatly resemble the hexagonal cells of the honeycomb if the double arrangement of the comb be left out of sight (Plate xl., Figs. 1, 2, p. 63).

Similar hexagonal columns are seen in hydrated starch; the result of shrinkage in the original moist, amorphous, starchy mass (Fig. 19, p. 64). There is, however, this difference; the rock and starch hexagonal columns are solid, and are due, not to pressure, but to shrinkage. The one is a physical, the other a vital process.[1]

The production of the hexagonal cells of the honeycomb, moreover, is not due to a pressure of growth or the mere expansion of substances capable of developing and increasing in a confined space, but to constructive power inhering in the bees themselves. The bodies of the bees do not swell when they are engaged in building the double row of hexagonal cells which forms their comb. On the contrary, they leave themselves sufficient space to turn about freely in the cells, and so employ their head, jaws, feet, and other parts of the body when engaged in the cell and comb formation. Hundreds of bees are at work at the same instant, and more than one bee takes part in the formation of a cell. As a matter of fact, the bees work in relays and according to a common plan, which, however, admits of modification under certain circumstances. The bees have first to produce the wax and the propolis (resin or bee-glue) required for every form of cell and comb construction. They have then to determine where the propolis and wax are to be placed, and in what proportions. These materials are not unfrequently employed in producing supporting structures in peculiar positions, and where portions of comb threaten to fall or be broken off. There is, it might be urged, no reciprocal pressure in the construction of the spider's web, the ant's nest, or the nests of fishes and birds.

The building materials being ready, a joint start is made by hundreds of bees, which all work at the same time according to a fixed plan, and in a given direction. To this end the bees first of all deposit the wax and place themselves at measured distances from each other. These are voluntary acts. They also arrange themselves into two great sets, head to head, to produce the double comb (comb composed of two sets of hexagonal cells). This is not only a voluntary act but one which clearly carries with it prevision, or a comprehension of the end to be attained. They also (and this is a very remarkable circumstance) leave spaces or passages between the combs to admit of the bees coming to and going from the cells of the combs when finished. Here there cannot possibly be a question of pressure. It is a clear example of design and intelligence on the part of the bees, or the Worker behind the bees. If pressure be credited with the construction of the hexagonal cells of the double comb, it cannot, even remotely, be associated with the formation of passages between, and in many cases through, the combs.

If the surfaces to which the combs are to be attached are smooth, an extra amount of propolis or bee-glue is laid down to secure a proper basis of support. Here, again, a knowledge similar to that possessed by human builders is apparent. There is nothing accidental in the constructive arrangements.

[1] Other examples of change of shape caused by the exigencies of space are seen in the convolutions of the grey matter of the brain: in the air cells of the lungs; in the convoluted tubes of the kidneys, &c. The crumpling up and reduplication of parts in the brain, lungs, and kidneys are elaborations to given ends, and eminently indicative of design. They are not instances of mere mechanical crowding due to accident. They represent organs at their best, structurally and functionally.

Then as to the actual work, it is in every sense intelligent. The two sets of bees place themselves at equal distances, head to head, to form the double comb. They marshal themselves as accurately for the double function as if they were soldiers on parade. Wax and propolis being provided, they commence operations spontaneously and consentaneously. The bees do not hustle or incommode each other. There is no pressure of bee against bee. Each works within its own prescribed territory and performs its appointed task. This it may do either by itself or with assistance ; it being possible for more than one to work at the same cell consecutively. Some bees produce round cells and a single comb, but the domestic or hive-bees, taught doubtless by the circumscribed limits of the hive to economise space and material, produce hexagonal cells with prismatic bases and a double comb. It is here that the superior intelligence of the hive-bees shines out. Each bee of the hive, being duly impressed with the necessity of economising space and material, works accordingly. Each bee, having spaced and placed itself, works towards its neighbours all around. By a mutual process of feeling, well understood by them, they work towards each other at every point, with the result that they produce not simple round cells, but complicated hexagonal cells, with prismatic bases which are mathematically exact. As they work consentaneously on either side of the comb, and at a given speed, the cells are, for the most part, absolutely symmetrical. What would be round cells are made hexagonal cells by the bees, duly placed or separated, working towards each other at a given rate. The angles of the cells are not the result of mechanical indentation or pressure from without, but of intelligent graduated pressure from within ; there being room in each cell to give the parts of the bee, engaged in modelling the cells, free play. The intelligence of the bees is perhaps most manifest in the arranging of themselves into two sets to produce the double comb, in the placing of themselves at mathematically equal distances, and in the adhesion to a general plan of construction settled from the first.

These various " means to ends " are either traceable to a First Cause or are the result of education, experience, reflection, and reasoning power possessed by the hive-bees of the present day. They cannot be referred to blind instinct apart from reason in the individual and in the race. From the outset reason has been at work. The bees have arrived at their present intellectual standpoint in cell and comb construction, and in the general working and management of the hive, precisely in the same way that men have reached their present intellectual standpoint in building cities, forming communities, governments, and nations. The amount of intellect is due, in both cases, to accretions or accumulations of reasoning power, and these accretions or accumulations are, in every instance, due to experience, education, reflection, memory, and judgment, however rudimentary at first. The term instinct, if dissevered from reason, past or present, explains nothing.

That the hive-bees of the present day do reason, and reason accurately, in the matter of construction is proved beyond doubt by their changing and modifying their general plan under extraordinary circumstances as occasion requires. They have been known, when from some miscalculation one comb has threatened to run into another comb and destroy the bee-passage or highway, to deflect the transgressing comb and so preserve the passage. This necessitated a change in the comb as a whole, and more especially in the cells of the comb in the immediate vicinity of the deflection. They have also been known to repair a broken comb, and to buttress and support, by walls and props of wax, parts of combs which bulged and threatened to fall out. In such cases they have provided temporary supports, which were removed when the real supports were finished. It has happened that, when obstructions have been wilfully placed to prevent and hinder comb formation, the bees have surmounted the difficulties in the most ingenious, practical, and business-like manner. Thus F. Huber made the top and bottom of a hive of smooth glass. As the bees dislike a smooth surface as a basis of support for their combs, they built their combs, not from the top and bottom of the hive as is their wont, but from the side of the hive and horizontally. F. Huber, thinking to outwit them, made the opposite side of the hive also of glass. The bees perceived the new difficulty, and avoided it in advance, or before it was really encountered.

They deflected the horizontal comb, and carried it round to another portion of the side of the hive, and so avoided the glass portion, which would not have yielded a secure or satisfactory fixing for the comb. This necessitated an entire change of front ; the bees voluntarily twisted and bent their comb, and in so doing they modified all the cells in the vicinity of the deflection, many of them being made larger sized and pyramidal as well as hexagonal.

Other examples of reasoning and adaptation in comb formation are seen in the union of different parts of combs to each other. In such cases the uniting cells are often irregularly shaped. Further, and as has been already stated, the cells for the drones or male bees are larger than those for the workers or female bees. The cells for queen bees are, moreover, larger than those for males. All this bespeaks prescience and prevision. The sizes of the males and queens must be known and remembered, otherwise the cells would be misfits, which they never are.

The production of large cells for queens, and the feeding of ordinary workers, grubs, or larvæ upon royal food

to make big queen bees before the larvæ are three days old, is no accident. The queens are fed and housed intentionally and for a purpose, and if they are not required they are abandoned or destroyed.

Mr. Darwin practically adopted M. Buffon's view, but took his initiative from Mr. Waterhouse, who was of opinion "that the form of the cell stands in close relation to the presence of adjoining cells." Mr. Darwin proceeds on the principle of gradation. He says humble bees make very irregular rounded cells of wax; that the Mexican *Melipona domestica* forms a regular waxen comb of cylindrical cells in which the young are hatched, and some large cells of wax for holding honey which are nearly spherical, of nearly equal size, and aggregated into an irregular mass; that the cells of "the hive-bee" are hexagonal in shape and placed in a double layer. He adds: "Reflecting on this case, it occurred to me that if the Melipona had made its spheres at some given distance from each other, and had made them of equal sizes, and had arranged them symmetrically in a double layer, the resulting structure would have been as perfect as the comb of the hive-bee."

Mr. Darwin, it will be perceived, assumes everything. He does not explain how the hive-bee makes its cells at given distances, of equal size, and in a double layer. This, however, is the kernel of the whole matter. The hive-bee makes hexagonal, symmetrical cells, and no other bee does so. If the hive-bee has been taught by experience, reflection, and the exigencies of the confined space incidental to the hive, it should be credited with the perfection of its architecture so laboriously and successfully consummated.

Mr. Darwin endeavoured to prove his theory of the construction of the hexagonal cells by placing artificial plates of wax in beehives. He believed that the bees made their cells by excavating a number of little circular pits at equal distances from one another, and that when the pits acquired the width of an ordinary cell the sides of the pit intersected. When this occurred the bees ceased to excavate, and instead began to build up flat walls of wax on the lines of intersection. This, however, may simply mean that the bees availed themselves of the artificial wax supplied, and constructed their comb of hexagonal cells on the usual and approved pattern. Mr. Darwin sums up as follows: "The work of construction seems to be a sort of balance struck between many bees, all instinctively standing at the same relative distance from each other, all trying to sweep equal spheres, and then building up, or leaving ungnawed, the planes of intersection between these spheres."

The summing up throws no additional light on the problem. The questions have still to be put and answered: Why do the bees stand at equal and relative distances from each other? Why do they try to sweep equal spheres? Why do they build up or leave ungnawed the planes of intersection, and why do they build double combs at all?

That the hive-bee is an intelligent worker is not denied by Mr. Darwin. Thus in his "Origin of Species" (p. 225) he says: "It was really curious to note in cases of difficulty, as when two pieces of comb met at an angle, how often the bees would pull down and rebuild in different ways the same cell, sometimes recurring to a shape which they had at first rejected."

Büchner gives many examples of intelligent adaptation on the part of hive-bees. Thus he remarks: "All the cells have not the same shape, as would be the case if the bees in building worked according to a perfectly instinctive and unchangeable plan. There are very manifold changes and irregularities. Almost in every comb irregular and unfinished cells are to be found, especially where the several divisions of a comb come together. . . . At these lines of junction it is impossible to avoid irregular cells between the pressed together or unnaturally lengthened ones. The same is true more or less of the passage cells, which are made to unite the large cells of the so-called drone wax with the smaller ones of the working bees, and which are generally placed in two or three rows. . . . Finally, in places where special conditions of the situation do not otherwise permit, it may be observed that the bees, far from clinging obstinately to their plan, very well understand how to accommodate themselves to circumstances not only in cell-building, but also in making their combs."

That the perfected hexagonal cells with their three-sided pyramidal bases are, within limits, the outcome of reason and experience extending over long periods seems all but certain from the history of bees as a whole.

The humble-bee makes large, rounded, irregular cells which are not hexagonal-shaped. These bees are sometimes solitary and sometimes social. In the latter case agglomerations of large irregular cells are met with. The humble-bees are not "cabin'd, cribb'd, confined" as regards space.

"The mason bee closes the roof of its larval cell with a kind of cement, leaving only a little hole for feeding the young. In Algiers these bees not unfrequently utilise empty snail-shells. They also clean out and reoccupy old cells. They sometimes fight for and occupy their neighbours' cells. E. Menault asks: 'Does the mason bee act like a machine when it directs its work according to circumstances, possesses itself of old nests, cleanses and improves them, and thereby shows it can fully appreciate the immediate position? Can one believe that no kind of reflection is here necessary?'

"The carpenter bee makes a long cylindrical tube in wood, and divides it into a number of chambers by cross partitions composed of sawdust and saliva. In each chamber it places an egg with a stock of pollen to feed the

larva. In the first or oldest cell the bee bores a hole which communicates with the outer air, by which when the larva is hatched it escapes. Each larva in succession, and according to its age, bores a hole for itself through the partition next the oldest chambers, and so makes its exit in a certain order. The remarkable thing is that the larvæ always take the right direction, so that they never bore into and destroy each other.

"The tapestry bee, as its name indicates, clothes the walls and floor of its chamber with several layers of the petals of the poppy carefully smoothed. The chambers for the larvæ which are so clothed are dug in the earth, and are from three to four inches deep. When completed they are covered over with loose earth to prevent discovery. Here the capacity for construction is well marked, and an advance on the mason and carpenter bees.

"The nest of the carding bee is composed of a layer of wax surrounded with a thick covering of moss. The remarkable thing in this case is that each bee does not find and carry its own moss. This is done by a combined effort; the bees arranging themselves in line and transmitting the moss from the part where it is discovered to the nest, which is guarded to prevent the ingress of ants and other insects. Some ants adopt a similar mode of transmission."[1]

Wasps display similar intelligence in nest construction. They construct them of wood dust mixed with saliva to form a kind of paper, which is for the most part waterproof. They even appropriate pieces of thin, soft paper if they come in their way. They thus show considerable adaptive ingenuity and skill. The wasps do not store honey for the winter. Their cells are consequently only constructed for rearing larvæ. The cells are sometimes round, but more frequently hexagonal, as in hive-bees. The combs differ in that the combs of the wasp are single instead of double. The wasp is remarkable in this, that it can construct round and hexagonal cells with equal facility. This goes to show that cell construction is the result of a spontaneous and voluntary effort, and therefore not traceable to pressure, to heredity, or to instinct, as commonly believed.

The mason wasps construct their nests of clay. The nests are suspended from the branch of a tree, and stocked with spiders and insects paralysed by stinging, which, being alive, keep fresh until the larvæ are developed and they are required as food. The butcher wasps also paralyse their victims by stinging. The remarkable habit of mason and butcher wasps paralysing their prey by stinging, and so keeping them alive and fresh until they are required as food for their young, is one of the most extraordinary facts in nature. The habit can only have been acquired by observation and experience, and a process of reasoning extending over long periods of time. According to Mr. Mivart, it cannot be explained on Mr. Darwin's theory concerning the origin of instinct.

Mr. Darwin experienced a similar difficulty in connection with the so-called instinct of neuters, where the individuals can derive no benefit from heredity or transmission by sex. Much might be added to the foregoing as to the intelligence possessed by bees and wasps.

The bees of the same hive are believed to be able to recognise each other. This they do, according to Mr. Langshaft, by the sense of smell. It should not, however, be forgotten that bees have excellent eyes, and that they are capable of emitting a great variety of sounds which can be intelligently interpreted. According to one writer, bees have a whole gamut of sound, "ranging from profound delight to menace, distress, and anger."

On one occasion I myself enraged a wasp in a room by flicking it with a handkerchief. Its note rose considerably in pitch, and I felt I was in danger of being stung by it.

Both bees and wasps raise the pitch of their notes when their hives are attacked. I can never forget an alarming episode which befell a small nephew of mine at Wexford, Ireland, in the autumn of 1873. I was sitting in the garden writing an introductory lecture, and, as there were several hives of bees in the upper part of the garden I said to the child—a boy of five years—"Now, Jackie, don't go near the bees." He promised obedience, and I went on with my writing. Presently the child came rushing down the central walk screaming with pain and fear, and with a cloud of angry bees around him. These I dispersed with much trouble and at no little risk to myself. He was badly stung on the face and neck. What had happened was this. He had taken a long twig, and, inserting it into the entrance of the hive, had deliberately poked the hive up. The bees, disturbed and enraged, at once sallied forth and attacked in force, uttering, as they did so, their strident war note. Bees have been known to kill horses, cattle, and other large animals under similar circumstances. The careless upsetting of a hive is especially provocative and dangerous.

I have good reason to remember a boyish escapade of my own with wasps in the forties. I was sent on a message to Monkland House, Lanarkshire, a most beautiful and romantic spot, with the river Calder running near. There was a sunny bank overhanging the stream, and from its soft, mossy surface a veritable ribbon of gold issued. It was a strong wasps' nest in abnormal activity. The temptation was too great for me. I slipped into an adjoining copse and cut a fine bunch of broom, and with it, single-handed, assailed the nest. I belaboured it until I had no strength left. When I had got quit of my surplus energy and done marked injury to the hive I was minded to

[1] Bingley, "Animal Biography," vol. iii. pp. 272–75.

retire, as I thought, victoriously: but no; my retreat was vigorously contested, and, ultimately, quickened. Several wasps furiously and fearlessly whirled round my head and kept dashing at my face. The situation was decidedly uncomfortable, and, feeling that, under the circumstances, discretion was the better part of valour, I ignominiously took to my heels. I ran, and better ran, down stream, but all to no purpose. One infuriated, persistent wasp, on mischief bent, kept its position in front of me. Breathless I reached a fence, where I was obliged to pause, as it was too high to be negotiated on the run. The instant I stopped, my assailant plunged its sting into the corner of my left eye at the root of the nose. It had its revenge and I had mine. I squelched the offending insect *instanter*. Both eyes began to swell at once, and the swelling increased to such an extent that I was rendered blind for three days. During the three days in question, the sound of even a bluebottle fly in the distance alarmed me. As Shakespeare has it, "Conscience doth make cowards of us all." That lesson has lasted me a lifetime.

Herr Huber found that if a beehive be attacked and plundered by the death's-head moth (*Acherontia atropos*), the bees, after several incursions of the marauder, erect a barrier of wax and propolis to exclude him. The barrier is reared just behind the gateway of the hive, and is provided with a small aperture large enough to admit a bee, but much too small to admit the despoiler. The rearing of the barricade, Huber points out, could not be due to instinct, which would have induced the bees to protect themselves against a first attack. Seeing it was only raised after several attacks he concludes that it was the outcome of experience, deliberation, and reason. He instances another example of reasoning power on the part of the bees. A piece of comb in a hive fell down and was fixed in its new position. This done, the bees proceeded to strengthen the attachments of all the other combs to prevent a recurrence of the original catastrophe. He exclaims, and not unnaturally, "I admit that I was unable to avoid a feeling of astonishment in the presence of a fact from which the purest reason seemed to shine out."

On another occasion, according to Dr. Brown, a central comb in a hive, being overburdened with honey, broke loose, and was pressing against another comb in such a way as to destroy the passage reserved for the bees between the combs. The accident occasioned great tumult in the hive. The bees, however, were equal to the occasion. They constructed two horizontal beams of wax to support and buttress the fallen comb, and removed so much honey and wax above as to admit of the passage of a bee. By these means the offending comb was ultimately secured at another point. The bees (and this is the amazing thing) thereupon proceeded to remove the two original horizontal bars, which were plainly temporary structures. These operations extended over some ten days, and during that long period the bees worked intelligently and to a given end.

Sir Benjamin Brodie[1] cites yet another example where a large portion of a honeycomb had broken off and become fixed in the middle of the hive. The bees on this occasion did not erect horizontal supports, but a vertical one, resting on the floor of the hive. They united the injured comb, propped up as explained, to the broken comb above, and when this was done they removed the vertical support, clearly showing that it was a temporary structure from the first.

Dr. Dzierzon, a most intelligent bee-keeper, writes as under: "The cleverness of the bees in repairing, perfectly, injuries to their cells and combs, in supporting on pillars pieces of their building accidentally knocked down by a hasty push, in fastening them with rivets, and bringing everything again into proper unity, making hanging bridges, chains, and ladders, compels our astonishment."

Herr Büchner relates a case where the wind overturned a hive and detached a comb when the bees were hard at work. The owner replaced the comb and fixed the hive securely. The bees, however, forsook the hive, fearing a recurrence of the catastrophe.

Hive-bees transported to Australia and California, where flowers are in bloom all the year round, cease to collect honey for the winter, and become idle after a few years.

Bees and wasps come to know those who are fond of them and work among them.

Bees, when the corollas of flowers are too long to admit of their reaching the honey, deliberately bite through the bases of the corollas. This I have myself witnessed on several occasions. The humble-bee, M. Jervoise remarks, cuts his way out if imprisoned in the flower of the foxglove.

Bees display great intelligence in keeping their hives sweet. They never void their excrements within, but always outside the hive. If overtaken with a kind of dysentery, to which they are subject, and which not unfrequently decimates the hive in severe winters and when food is scarce, they set apart a portion of the hive which communicates with the outer air for excreta. They also avail themselves of the first fine day to rid themselves of a nuisance, and, in spring, take a cleansing flight.

When snails, mice, and other intruders effect an entrance into the hive they are destroyed and covered over with propolis to prevent them from decaying and smelling. If this is not sufficient the putrescible parts are gnawed away and carried outside the hive. Dead bees are also removed from the hive. In very hot weather, when the

[1] "Psychological Inquiries," 1854, p. 88.

wax of the hive is in danger of being melted, the bees collect in masses *outside* the hive to keep down the temperature.

Bees ventilate and keep the hive at a comfortable temperature by a very rapid fanning movement of their wings —this task being performed by the bees in relays. The fanning, as Huber points out, is not instinctive, for it ceased when he supplied the bees with very large hives, namely, five feet high. The fanning is a spontaneous, voluntary movement instituted to overcome the difficulty occasioned by the bees being confined in small, and it may be hot, spaces, as happens in ordinary hives.

All that is stated above favours the existence of reasoning powers in bees, however acquired. The whole economy of bees points to the obtaining, storing, and transmitting of knowledge ; the knowledge being, in some cases, as curious as it is remarkable. Bees make queens at discretion and regulate the number of queens and males ; they lay up a stock of honey against winter, and avail themselves of artificial conditions in the matter of food and the building of their hives when these are to their advantage. They accommodate themselves to circumstances as regards climate, and build their nests in trees and hollow places with no protective coverings in mild and dry climates, whereas in moist, cold climates they search out watertight tenements and provide waterproof roofs. They carry out the principle of division of labour to an extraordinary extent. Some are set apart for procreative purposes, and these are killed off when in excess or when they have fulfilled their mission. The male and queen bees perform no work in the ordinary sense. The female or working bees are the "hewers of wood and drawers of water" for the community, and display an amazing amount of activity and industry. From sunrise to sunset they toil contentedly and ungrudgingly. They are parsimonious as regards their own comforts. All their spoils of honey and pollen, carried, in many cases, enormous distances, are lavishly piled up for the inmates of the hive as a whole, and for the common good. The beautiful hexagonal cells, built with extreme care and mathematical precision, are employed for the accommodation of the larvæ, or the storage of honey and pollen, according to circumstances. Every part of the hive has its uses and is turned to account. Honey is stored in sufficient quantity to provide food during the long winter and early spring. How all this comes about I do not pretend to explain. I have, however, no difficulty in believing that bees work intelligently, and are not goaded into activity by blind chance. Either, as previously stated, the Creator works in and through the bees, or they work intelligently in virtue of the brain and nervous system with which the Creator has endowed them. In bees, as in animals generally, provision is made for progress within limits. The bee, however, cannot develop beyond a given point. There are grades of bees, as of every living thing, and improvement within each grade—the type or fundamental form remaining constant. The typical forms are not evolutions the one from the other. The domestic bee, with its double honeycomb, is the highest representative of the highest type of bee, and it has improved itself by intellectual efforts in a great many directions. Similarly, man is the highest representative of the highest type of quadrumana. Man is not, however, to be regarded as the direct or indirect product of any form of man-like ape. He is a typical animal, and, in that sense, a separate creation. How many ages have passed since the bee began to take cognisance of facts, and to act upon them, cannot be determined, but the history of the bee indicates progress and civilisation of a kind. The arrangements of the hive, at the present day, involve the combined experience of millions of workers for incredibly long periods. The bee and its honeycomb have figured on Egyptian temples, tombs, monuments, obelisks, sarcophagi, mural slabs (stelæ), papyri, &c., for five or six thousand years at least. The representations of these historical bees I have carefully examined (1904–5) in the great Cairo Museum and for one thousand miles up the Nile. While domestic bees have not progressed for five or six thousand years, it was not, prior to that period, a case of endless and slavish repetition of certain acts. There has been repetition with modification and progress during the period. The brain and nervous system of the bee have undergone a slow process of elaboration and differentiation, and represent the aggregate knowledge, power, and resources of the highest type of bee. The bee, wonderful as it is in its many-sidedness, is not more so than the ant, which has a similar and even more extraordinary history, and which, in some respects, displays a higher intelligence. There can scarcely be a doubt that the powers erroneously classed under "instinct" in bees, ants, spiders, and various other animals are intellectual in their nature, and are the outcome of reason in some form or other. As the term instinct cannot be defined it should never be employed even in common parlance. It can only mislead. As far as I am personally concerned I am wholly opposed to its use in any and every form. Indeed I am fully convinced that, strictly speaking, there is no such thing as instinct.[1]

Similar remarks may be made of reflex action. It has no separate existence apart from theory.

Remarkably good examples of accretions of knowledge, treasured and transmitted by innumerable individuals over long periods, can be afforded by the migration of birds, their long, unerring flights in space, where no landmarks are visible, in all probability dating back to a period anterior to the formation of the great continents and the great seas which now separate them. It is easy to understand how birds by short flights followed the sun, and

[1] For definitions of instinct, see p. 874.

the ample supplies of food, vegetable and animal, produced by genial climes when there was continuity of land, with numerous landmarks and narrow seas. It is next to impossible to realise the practically interminable flights of migrating birds over wide seas in the absence of landmarks, and with no chart other than that supplied by the brain, and their own extraordinary sense of direction. Many animals share this latter property with them. The continuity in the habits of migratory birds finds a partial solution in the fact that the several races of birds have existed from the earliest times, and each race in succession has transmitted and added to the knowledge required for the migratory flights. There is neither mystery nor divination in these flights. There is, however, knowledge which comes of observation, experience, and reasoning.

One of the most extraordinary examples of accumulated knowledge and reasoning is supplied by the Californian woodpecker. This remarkable and interesting bird stores up during the autumn a supply of acorns for winter consumption. Its manner of doing so is extremely ingenious. It makes lines of round holes in the bark of a tree, and accurately places in each an acorn of appropriate size. The woodpecker has learned two things: (*a*) that it requires food in the winter when food is scarce, and (*b*) that acorns preserved according to its peculiar plan will be available (Fig. 226, p. 832, illustrates this point).

Wasps are in some respects more clever than bees. The Rev. J. W. Mossman on one occasion discovered a fallen apple in his orchard full of these insects. There was only one small aperture in the apple through which they entered and retired. In every instance the wasps came out tail first, brandishing their stings. If they had come out head first they might have been taken at a disadvantage and picked off by birds or destroyed.

Mr. Seth Green once saw a wasp circumvent and destroy a large spider and its brood of young. The wasp literally baited the spider by coolly wriggling one of its antennæ in front of its hole. When the spider darted out to see what was going on, the wasp dexterously stung it to death. It repeated its tactics, but as no more spiders came out it entered the nest and carried off the young spiders one by one.

The hunting wasp pursues and kills spiders systematically.

Consul Merlin one summer afternoon observed a spider run across the window-sill of his bedroom in a crouching attitude and hide itself under the projecting edge of the sill. Presently a very fine specimen of the hunting wasp buzzed in at the open window and flew about the room, evidently in search of something. It soon settled on the window-sill and coursed backwards and forwards like a dog until it caught the trail of the spider, which it pursued and stung. The spider took refuge under the bed, and was again discovered by the wasp, which circled round it like a hound, apparently by sight. The poor spider was chased from place to place until it finally succumbed to repeated stings. The wasp then attempted to carry off its prey, but was prevented by the consul, who secured it and the spider for his collection.

Dr. Erasmus Darwin [1] records a case where a wasp on the ground was endeavouring to remove a large fly which, however, proved too heavy for its strength. The wasp, not to be denied, cut off the head and abdomen of the fly and flew away with the thoracic portion. As ill luck would have it, the wind caught the wings of the fly, which still adhered to the thorax, and made the removal difficult. The wasp, equal to the new difficulty, deposited the thorax on the ground and deliberately tore off the wings, after which it flew off with its booty.

A friend of my own had a similar experience at his shooting-box in Stirlingshire, Scotland. In the sunny porch of the house in autumn it was a common occurrence to witness wasps hunting and killing bluebottle flies. The first thing the wasps did on securing their victims was to deprive them of their legs and wings. Thus mutilated they bore them off in triumph, and more easily than one would have thought possible.

Mr. R. S. Newall [2] describes an encounter between a wasp and a caterpillar. He writes: "Many years ago I was examining an apple tree, when a wasp alighted on a leaf which formed a caterpillar's nest neatly rolled up. The wasp examined both ends, and finding them closed, it soon clipped a hole in the leaf at one end of the nest about one-eighth of an inch in diameter. It then went to the other end and made a noise which frightened the caterpillar, which came rushing out of the hole. It was immediately seized by the wasp, who, finding it too large to carry off at once, cut it in two and went off with his game. I waited a little and saw the wasp come back for the other half, with which it also flew away."

Herr Albert Schlüter, writing from Texas, narrates a case where a cicada was pursued by a large hornet. The hornet overtook its victim, and threw itself upon it and stung it to death. "The murderer walked over its prey, which was considerably larger than itself, grasped its body with its feet, spread out its wings, and tried to fly away with it. Its strength was not sufficient, and after many efforts it gave up the attempt. Half a minute went by: sitting astride on the corpse and motionless—only the wings occasionally jerking—it seemed to reflect, and indeed not in vain. A mulberry tree stood close by, really only a trunk—for the top had been broken off, clearly by the last flood—of about ten or twelve feet high. The hornet saw this trunk, dragged its prey toilsomely to the foot of

[1] "Zoonomia," vol. i., p. 183.

[2] *Nature*, vol. xxi., p. 494.

it, and then up to the top. Arrived thereat, it rested for a moment, grasped its victim firmly, and flew off with it to the prairies. That which it was unable to raise off the ground it could now carry easily once high in the air."

Mr. T. Meehan[1] observed a very similar case with *Vespa maculata*. He saw one of these wasps try in vain to raise from the ground a grasshopper it had killed. When all its efforts proved to be in vain, it pulled its prize to a maple tree, about thirty feet off, mounted it with its prize, and flew away with it. "This," adds the writer, "was more than instinct. It was reflection and judgment, and the judgment proved to be correct."

The examples given of intelligence in insects—spiders, ants, bees, wasps, &c.—are so numerous, so striking, and so mutually confirmatory as to leave no doubt in my mind that insects are endowed with reasoning powers. What especially strikes me in this connection is that such tiny creatures, with comparatively rudimentary nervous systems and brains, should display so much resource and practical wisdom. Individually, and in the aggregate as social communities, their actions reveal a degree of decision, precision, and unity of purpose which is only paralleled in the highest animals, man included.

I cannot help feeling that quite extraordinary powers must be conceded to even the most minute specks of nervous matter. The brain of the ant, a scarcely visible object, is to be credited with resource, invention, strategy, memory, judgment, and reasoning power generally. It displays also a cognitive or knowing faculty and a dim consciousness. All the mental powers possessed even by man are clearly foreshadowed. The movements and actions of ants are spontaneous and voluntary, and are in no sense indirect, reflex, or instinctive. They are, moreover, not due to irritability or extraneous stimulation.

The brain and nervous system of the ant, and of insects generally, in no way differ from the brain and nervous system of the higher animals and of man. The only distinction that can be made is one not of kind, but of degree. The brains and nervous systems of the highest animals are more elaborate, but this is all that can be said. Brain matter and nerve matter, wherever found, are fundamentally the same. There is no break or breach of continuity. There is a common plan for the nervous as for all the other systems in animals. The nervous system in animals may be likened to a chain. Fresh links are added according to the degree of differentiation attained, but the links, if here and there stronger and slightly diversified, are forged according to a plan which is never really departed from. In this and in no other way can the reasoning powers undoubtedly possessed by animals be assimilated with those of man. The old idea, that man was separated from the higher animals by an impassable gulf, mainly and chiefly intellectual, cannot, in the light of modern science, be maintained. He is the head of a class, and can be separated from the monkeys (his nearest allies), as the monkeys are separated from each other and from other animals, but the brains, bones, muscles, &c. of monkeys are indistinguishable microscopically, chemically, and otherwise from those of the genus *Homo*.

The nervous system structurally and functionally reveals differentiation and progress as we ascend from the lower to the higher and highest animals; but there is oneness and continuity as to mental manifestations; these standing to each other in the relation of simple, slightly complex, complex, and very complex. An example of the simple nervous system is seen in the jelly-fish; an example of the very complex in man.

Between these extremes an infinite number of graduated nervous systems are encountered. That they differ less in kind than in degree is proved beyond doubt by a careful examination and analysis of the intellectual faculties displayed by animals in an ascending series up to man.

I will therefore now adduce additional examples of what I regard as reasoning powers in animals occupying, for the most part, higher platforms than those occupied by insects.

INTELLIGENCE OF FISHES, BATRACHIANS, REPTILES, AND BIRDS

§ 260. The Intelligence of Fishes.

These are the lowest representatives of the great vertebrate series, man being the highest. They possess a brain, spinal cord, and sensory and motor nerves. The cerebral lobes of the fish, while comparatively very small when contrasted with those of the highest vertebrates, are nevertheless enormous as compared with the œsophageal ganglia or brain of an insect; a state of matters which is emphasised when the cerebral hemispheres of the fish are contrasted with their analogues in the brain of the ant, to wit, the pedunculated and convoluted lobes surmounting the cephalic ganglion. The question of quality as against quantity of brain substance here comes in, and this question, it will be found, crops up continually in members of the same family.

While the brain volume of the fish greatly exceeds that of the insect, it does not do so relatively; the insect having

[1] *Proc. Acad. Nat. Philadelphia*, January 22, 1878.

more brain according to its size and weight than the fish. The brain of the insect is, moreover, organically more perfect and more highly differentiated. Von Baer was of opinion that a bee is as highly organised an animal as a fish, and to this view, if its psychological side only be considered, no valid objection can be taken. The question which here emerges is as to the standard of organisation. Is it to be a standard of brain and nerves, or of bones, muscles, glands, and substances more or less peculiar to the so-called highest animals? What is true of the brain of an insect and a fish is also true of the brain of a man and an elephant. An elephant has a larger and heavier brain than a man, but it is not larger and heavier when the aggregate weight of the elephant and the man are considered. The brain of the man is, moreover, of a better quality.

From what is here stated it will be seen that mere volume of brain or of nerve substance is not necessarily a measure and sign of intellectual capacity. Small, well-balanced heads are often more powerful than large, lop-sided ones.

Further, it does not follow that mere differentiation in an animal, unless it be of the nervous system, is to be regarded as a proof of higher organisation. By common consent the brain and nervous system are regarded as furnishing the highest manifestations of life. The perfection of the nervous system would seem to be the standard by which animals must ultimately be measured. If, then, the insect displays more intelligence than the fish, it is owing to its comparatively more highly differentiated nervous system.

The brain and nervous system of the fish are deserving of attention as forming a sort of starting-point for the great vertebrate series which culminates in man.

The brain of the fish is essentially, and to all intents and purposes, an expansion of the spinal cord. It consists of a double chain of ganglia arranged in nearly the same plane as the cord. The components of the chain, named from before backwards, are the two cerebral lobes, the two optic lobes, the cerebellum, and the medulla oblongata (see Plate lvii., Fig. 5, A, p. 133).

The fish displays no great degree of intelligence, and the movements of its several parts are comparatively simple.

The fish, nevertheless, reveals many of the peculiarities of the higher animals. Thus it exhibits social, sexual, and parental feelings; it can be frightened and enraged; it is jealous, curious, pugnacious, &c.; certain fishes are social and swim in shoals; salmon fight for the possession of the females. Sticklebacks and gobies build nests. Schneider at the Naples Aquarium saw several species protecting their eggs, the male mounting guard and displaying an open mouth against intruders, and I myself have seen the same thing not unfrequently in private aquariums. The nidification of fishes is similar, in some respects, to that of spiders, ants, bees, and even birds.

Mr. Mansfield showed Agassiz [1] a mass of sargassum the size of a child's head, composed of gulf weed elaborately knitted together by elastic threads, and containing a large number of eggs, evidently the work of the *Chironectes*. Here was an example of a floating fish nest which at once provided protection and feeding for the immature and helpless young.

The sticklebacks afford still more admirable examples of nest building. The following is the account given by Mr. Ransom [2] of the operation as conducted by the ten-spined stickleback (*Gasterosteus pungitius*): "On May 1, 1864, a male was placed in a well-equipped aquarium of moderate size, to which, after three days, two ripe females were added. Their presence at once roused him into activity, and he soon began to build a nest of bits of dirt and dead fibre, and of growing confervoid filaments, upon a jutting point of rock among some interlacing branches of *Myriophyllum spicatum*—all the time, however, frequently interrupting his labours to pay his addresses to the females. This was done in most vigorous fashion, he swimming, by a series of little jerks, near and about the female, even pushing against her with open mouth, but usually not biting. After a little coquetting she responds and follows him, swimming just above him as he leads the way to the nest. When he first courts the female, if she, not being ready, does not soon respond, he seems quickly to lose his temper, and, attacking her with apparent fury, drives her to seek shelter in some crevice or dark corner. The coquetting of the male near the nest, which seems due to the fact that he really has not quite finished it, at length terminates by his pushing his head well into the entrance of the nest, while the female closely follows him, placing herself above him, and apparently much excited. As he withdraws she passes into the nest, and pushes quite through it, after a very brief delay, during which she deposits her ova. The male now fertilises the eggs, and drives the female away to a safe distance; then, after patting down the nest, he proceeds in search of another female. The nest is built and the ova deposited in about twenty-four hours. The male continued to watch it day and night, and during the light hours he also continually added to the nest."

M. Carbonnier, dealing with Mr. Baker's observations on the three-spined stickleback in the *Philosophical Transactions*, furnishes some interesting information as to the hatching-out process. "After the deposition of the eggs

[1] *Silliman's American Journal*, "Fish," February 1872.

[2] *Annals and Magazine of Natural History*, 1865, vol. xvi., p. 449.

the nest was opened more to the action of the water, and the vibratory motion of the body of the male fish, hovering over its surface, caused a current of water to be propelled across the surface of the ova, which action was repeated almost continuously. After about ten days the nest was destroyed, and the materials removed; and now were seen the minute fry fluttering upwards here and there, by a movement half swimming, half leaping, and then falling rapidly again upon or between the clear pebbles of the shingle bottom. This arose from their having the remainder of the yelk still attached to their body, which, acting as a weight, caused them to sink the moment the swimming effort had ceased. Around, across, and in every direction the male fish, as the guardian, continually moved. Now his labours became more arduous, and his vigilance was taxed to the utmost extreme, for the other fish (two tench and a gold carp), some twenty times larger than himself, as soon as they perceived the young fry in motion, continuously used their utmost endeavours to snap them up. The courage of the little stickleback was now put to its severest test; but, nothing daunted, he drove them all off, seizing their fins and striking with all his strength at their heads and at their eyes. His care of the young brood when encumbered with the yelk was very extraordinary; and as this was gradually absorbed and they gained strength, their attempts to swim carried them to a greater distance from the parent fish; his vigilance, however, seemed everywhere, and if they rose by the action of their fins above a certain height from the shingle bottom, or flitted beyond a given distance from the nest, they were immediately seized in his mouth, brought back, and gently puffed or jetted into their place again."

The sticklebacks display quite an extraordinary amount of parental affection and authority, backed by remarkable courage and an intelligent appreciation of varying circumstances which can only be explained by the exercise of reason.

The Chinese butterfly fish (*Macropodus*) also builds a nest. This is chiefly composed of froth made in a very peculiar manner. The male fish sucks in bubbles of air at the surface of the water, and strengthens these with mucus from its mouth. When the nest is prepared the female is induced to enter and deposit her eggs. If any of the eggs by mischance fall to the bottom, they are elevated and replaced in the nest by means of currents of air ejected from the mouth and pharynx of the fish. The nest-building process and the treatment of the eggs equally bespeak intelligent action.

That fish have kindly feelings towards each other and are capable of affection is shown in various ways.

Mr. Arderon[1] tamed a dace, which used to lie close to the glass watching its master. He also kept two ruffs (*Acerina cernua*) which were much attached to each other; so much so, that when the one was removed the other refused to eat, and was very unhappy until its mate was restored to it. The same thing, according to Mr. Jesse, occurred with two gold carp. Mr. Jesse relates how he captured a female pike (*Esox lucius*) during the breeding season, and that the male pike could not be driven away from the spot where his mate had been taken out of the water.

That fish are at times jealous and angry is abundantly proved by the behaviour of the sticklebacks, and by salmon and other fish, which fight for the possession of the parturient females about to shed their ova.

That they are curious is shown by their being attracted by lanterns, flaming torches, and other bright objects. Their curiosity not unfrequently costs them their lives, fishermen and poachers spearing them while gratifying it. "Burning the water," as the phrase goes in Scotland, means the display of a flaming torch in salmon pools, and the striking and killing of the salmon when they appear by leisters, gaffs, and other implements. This mode of taking salmon, long recognised as an exciting, manly sport, is now considered illegal, and punished accordingly.

Fish, especially sea-trout, occasionally gratify their curiosity by repeated high leaps in the air. This I myself have witnessed on many occasions when fishing Highland lochs and streams. The leaps in question are not those of ordinary play. Their curiosity seems to be aroused by unusual sounds and noises, such as are produced by the splashing of oars in lakes or the movements of the feet on the banks of rivers.

That fish can, and do, appreciate sounds is proved in many ways. Sir Joseph Banks used to collect his fish by sounding a bell, and this indeed is a very ancient and common practice. Lacepède even relates that some fish, which had been for many years kept in a basin of the Tuileries, would appear when their names were called.

That fish are intelligent up to a point does not admit of doubt. In streams and lochs which are much fished by experienced anglers it is very difficult to take the trout. They have been educated by all kinds of artificial lures, and, being frequently pricked by hooks, are exceedingly cautious and wary. As one devoted to the gentle art, I have at times experienced the greatest possible difficulty in filling my basket in much-frequented streams and lochs, no similar difficulty being experienced in remote streams and lochs. I have occasionally encountered a similar difficulty with salmon. Both trout and salmon, when caught, do all in their power to get rid of the offending hook. They throw themselves out of the water and come down on the gut casting line, lash their tails furiously, rush across and up and down the pool, attempt to get into rapids, weeds, and bushes if near, rub their noses against

[1] *Philosophical Transactions of the Royal Society*, 1747.

every obstruction to try to get rid of the hook, and do all in their power to foul and break the line on snags (projecting rocks, stumps of trees, &c.). They also, if large, not unfrequently sink to the bottom and sulk, and positively refuse to move—a trying position for the angler who knows he has a good fish on.

These various attempts at escape are all intelligent in their way, and, unfortunately, very often succeed. The angler is always said to lose his best fish.

Fish, as a rule, are voracious, and greedily devour each other. They generally attack each other with a rush, but instances are not wanting where the fish exhibits the most exemplary patience, and even resorts to wiles in circumventing its prey.

The fishing frog (*Lophius piscatorius*) affords an example. This remarkable fish is provided with a huge head and wide jaws well stocked with teeth, a smallish, tapering body and tail, and a long, thin, elastic organ, like a small fishing-rod, which projects from the top of the head and terminates in a small mobile tuft. The fish buries itself in the mud and causes its thin, elastic-tufted organ to move gently to and fro. The tuft is the bait, and when passing fish are attracted by and attempt to secure it, they readily become a prey to the crafty angler.

Another example of strategy and intelligence is afforded by the jaculator fish (*Chelmon rostratus*). This curious creature literally stalks and shoots its victims. It feeds upon small flies and other objects which settle upon grass and vegetation near the surface of the water. When the fish perceives a fly or small living object so placed, it approaches gently, and when at a proper distance ejects from its mouth a drop of water with such force and precision as infallibly to displace and disconcert its quarry, which, falling into the water, becomes an easy prey. This mode of capturing food is scientific to a degree. It bespeaks a knowledge of cause and effect, and an appreciation of force and its consequences. A man could scarcely do better with a javelin, a bow and arrow, or a rifle. The eyes of the fish have to deal with two media—the air and the water—with different refracting powers, and the muscular movements which suck in and eject the water are graduated and are of the most delicate description. The fish and its ancestors had, no doubt, to learn by experience to view objects in air and in water, to take in and eject water with varying degrees of force, to take aim, to shoot suddenly, and to take advantage of the confusion caused by the discharge of the liquid bolt when its victim finds itself helpless in the water. The adaptations of means to ends displayed in this case are very obvious.

The intelligence of fish is not confined to capturing food. Thus certain species of fish in different parts of the world quit pools about to dry up and make excursions across country in search of an increased water supply. The common eel not unfrequently migrates from place to place, travelling by night and covering considerable distances.

According to Hancock, a species of *Doras* migrate at night in large shoals when searching for water. The fish, which are about a foot in length, have strong serrated arms, which constitute the first rays of their pectoral fins and act as travelling levers. By means of these levers and the tail, they hobble along almost as rapidly as a man can walk.

Bose found a migrating fish (*Hydrargyra*) in thousands in the fresh waters of Carolina. It proceeded by leaps, always in the direction of the nearest water. So accurate was its sense of direction that he could not, even by turning it round, induce it to travel away from the water.

The migrations of fish in water are a common occurrence, and are of two kinds, namely, those connected with the supply of food and those connected with spawning. Herrings migrate periodically in vast numbers, and salmon leave the sea and ascend fresh-water rivers to deposit their ova. During the latter operation the salmon, not unfrequently, travel enormous distances. They reach Switzerland by the Rhine, and Bohemia by the Elbe, and display extraordinary persistency and energy in overcoming obstacles such as rapids, cataracts, and water-falls. Professor Landmark found that in Norway a vigorous salmon can make a vertical leap of sixteen feet, a feat accomplished by no other animal, the kangaroo perhaps excepted.[1] I have often watched salmon attempting to leap the black linn on the Dochart, a tributary of the river Forth, in Scotland. The fish not only leapt vertically upwards, but they caused their bodies to make sinuous movements in the air similar to those made by them in the water, giving one the idea that they attempted to scale the insurmountable barrier by a combined leaping and swimming effort.

Salmon in the adult condition for the most part return to spawn in the same rivers in which they were originally hatched out. This has been proved by marking the salmon fry and young fish in various ways. The return of the fish to their respective rivers indicates a considerable degree of intelligence, especially where two salmon rivers, such as the Dee and Don in Aberdeenshire, Scotland, and the Sligo and Ballysodare rivers in Ireland, flow into the sea at short distances from each other. In these cases the salmon must observe and take the necessary bearings.

Mr. J. Faraday relates a case of intelligence in a large skate confined in an aquarium, which, being desirous of obtaining food which had fallen at an angle formed by the bottom and the glass front of the tank, placed itself obliquely above the food, and by a vertical fanning movement of its lateral fins created currents which raised the food to its

[1] The kangaroo can leap twenty-five feet, but not in a vertical direction.

mouth, situated on the under surface of its body. The position of the food and of the mouth prevented the skate seizing the dainty morsel directly, and it took the necessary measures to secure the desired result. My colleague, Professor W. C. M'Intosh, F.R.S., informs me that on one occasion, when he was dredging in the German Ocean near St. Andrews, a large skate was brought up in the dredger, which floundered about all over the dredger until it discovered an open part by which it escaped.

The carp, according to Kirby and Spence, sinks itself into the mud to escape the sweep of the net. If surprised on a shingly bottom it makes enormous leaps to free itself from the approaching danger.

Sharks and other fish often follow vessels for long distances in the expectation of having food thrown to them.

Pilot fish are believed to guide sharks to their quarry, and to give notice of possible trouble. Thus Captain Richards narrates a case where four pilot fish prevented a blue shark, for a time, from taking a bait thrown out to him from a ship, by which he was eventually captured. Some are of opinion that the pilot fish accompany the shark simply to enjoy the crumbs which fall from his occasionally bountiful table.

Cases are related where the thresher or fox sharks and the sword-fishes, having formed an offensive league, co-operate with each other in attacking and destroying whales.

Captain Arn, in a voyage to Memel in the Baltic, gives the following interesting narrative: "One morning during a calm, when near the Hebrides, all hands were called up at 2 A.M. to witness a battle between several of the fish called threshers or fox-sharks (*Alopecias vulpes*), and some sword-fish on one side, and an enormous whale on the other. It was in the middle of the summer; and the weather being clear, and the fish close to the vessel, we had a fine opportunity of witnessing the contest. As soon as the whale's back appeared above the water, the threshers, springing several yards into the air, descended with great violence upon the object of their rancour, and inflicted upon him the most severe slaps with their long tails, the sounds of which resembled the reports of muskets fired at a distance. The sword-fish in their turn attacked the distressed whale, stabbing from below; and thus beset on all sides and wounded, when the poor creature appeared the water around him was dyed with blood. In this manner they continued tormenting and wounding him for many hours, until we lost sight of him; and I have no doubt they in the end completed his destruction." A good example of a thresher shark is seen at Plate xlix., Fig. 2, p. 79.

§ 261. The Intelligence of Batrachians.

Frogs and toads can be readily tamed, and display intelligence of a kind. They are attached to localities, and return to them after being removed several hundred yards. Frogs have an extraordinary power of perceiving changes in the atmosphere, and of detecting moist places. Mr. Warden relates a case where a pond containing a large number of them dried up, with the result that the frogs made straight for the nearest water, although this was eight kilometres distant.[1]

Mr. Romanes gives the following account of a tame frog: "I used to open the gate in the railings round the pond and call out 'Tommy' (the name I had given it), and the frog would jump out from the bushes, dive into the water, and swim across to me—get on my hand sometimes. When I called 'Tommy,' it would nearly always come, whatever the time of day, though it was only fed after breakfast; but it seemed quite tame."

Mr. Pennant gives a similar account of a toad which lived in a state of domestication for thirty-six years, and knew him and all his friends.[2]

Mr. Tom Edward, the Scottish naturalist, credits frogs with considerable powers of observation. After referring to a great noise made by a number of them on a moonlight night, he remarks: "Presently, when the whole of the vocalists had reached their highest notes, they became hushed in an instant. I was amazed at this, and began to wonder at the sudden termination of the concert. But, looking about, I observed a brown owl drop down, with the silence of death, on to the top of a low dyke close by the orchestra."[3]

The Surinam frog accommodates and protects its young in pouches on its back, and the male toad (*Bufo obstetricans*) severs the gelatinous cord by which the ova are attached, and so performs the office of accoucheur to the female. These arrangements cannot be satisfactorily explained by mere instinct.

§ 262. The Intelligence of Reptiles.

The reptiles, although not remarkable for their intelligence, can in many instances be tamed, and display considerable affection. Thus the common guana (*Lacerta iguana*), which is naturally very gentle and harmless, can be roused into anger and made very valiant when the safety of its mate is threatened. Thompson says[4] "that when

1 "Account of the United States," vol. ii., p. 9.
2 Bingley, "Animal Biography," vol. ii., p. 406.
3 "Life of a Scotch Naturalist," by Dr. Smiles, p. 124.
4 "Passions of Animals," p. 229.

agitated by fear or anger its eyes seem on fire, it hisses like a serpent, swells out the pouch under its throat, lashes about its long tail, erects the scales on its back, and extending its wide jaws, holds its head, covered over with tubercles, in a menacing attitude. The male, during the spring of the year, exhibits great attachment towards the female. Throwing aside his usual gentleness of character, he defends her even with fury, attacking with undaunted courage every animal that seems inclined to injure her; and at this time, though his bite is by no means poisonous, he fastens so firmly, that it is necessary either to kill him or to beat him with great violence on the nose, in order to make him quit his hold."

The snakes in not a few places display considerable affection and intelligence. "Be ye wise as serpents and harmless as doves," is the injunction of Holy Writ, and wisdom somehow has become associated with these typical vertebrates.

Several snakes hatch out their eggs and are solicitous about their young—the young in certain cases being permitted to enter the body of the mother in case of danger.

Pliny speaks of the affection of asps for each other, and Sir Emerson Tennent asserts that, if a cobra be killed, its mate is often found for a day or two on the spot where the killing took place. Like affection, as already stated, is displayed by the pike under similar circumstances.

Snake charmers exercise great influence over snakes, and in some cases render then remarkably tame.

In the year 1901, at Tangier, Africa, I witnessed one of the dusky mountebanks perform with his snakes. He played on a soft-toned pipe, which apparently greatly delighted the reptiles, as they glided gracefully about and frequently raised their heads as if listening. One of them, more tame than the rest, he caused to lick his eyeballs. He also put its head into his mouth, and treated it in such a way as to show its complete docility.

Snake charmers often handle and subjugate the most poisonous reptiles, especially cobras. These they seize with great dexterity and cause to dance. If bitten, they burn the part with a small cautery which they have in readiness against accident. In some cases they apply snake-stone to the wound with, it is stated, a good effect.

A barrister friend of mine, a very careful observer, told me that when he was practising his profession in Singapore, a large cobra, which was being lassoed by his Chinese servants in a hen-house, which operation he was watching, ejected saliva in the form of a fine spray into his eyes, at a distance of five or six feet. The reptile, which was coiled up with its head and neck free and erect, and much excited and enraged by the attempts to catch it, suddenly took aim, with the result that immediately an impalpable cold moisture spread over his face and eyes; the latter at once becoming very greatly inflamed and exceedingly painful. The inflamed, painful condition of the eyes remained for several hours, but fortunately no greater evil ensued. My friend expressed the opinion that the venomous snakes eject saliva into the eyes of their victims when sufficiently near, and that this accounts for the perturbation and alarm which are set down to so-called snake fascination.

Sir Joseph Fayrer attributed the fascination to fear, and no doubt animals have a dread of their natural enemies; oxen, for example, trembling and lowing piteously when lions are in their vicinity. On the other hand, pigeons and rabbits introduced into cages of pythons and rattlesnakes, after a temporary alarm, settle down, feed, and seem quite happy. This I have again and again witnessed in the Zoological Gardens, London.

Mr. Pennant and Le Vaillant both testify as to the fascinating power of snakes.

Thus Pennant says: "The rattlesnake will frequently lie at the bottom of a tree on which a squirrel is seated. He fixes his eyes on the animal, and from that moment it cannot escape; it begins a doleful outcry, which is so well known that a passer-by, on hearing it, immediately knows that a snake is present. The squirrel runs up the tree a little way, comes down again, then goes up, and afterwards comes still lower. The snake continues at the bottom of the tree with its eyes fixed on the squirrel, and his attention is so entirely taken up, that a person accidentally approaching may make a considerable noise without so much as the snake turning about. The squirrel comes lower, and at last leaps down to the snake, whose mouth is already distended for its reception."

Le Vaillant, in like manner, avers that "he saw on the branch of a tree a species of shrike, trembling as if in convulsions, and at the distance of nearly four feet, on another branch, a large snake that was lying with outstretched neck and fiery eyes, gazing steadily at the poor animal. The agony of the bird was so great that it was deprived of the power of moving away; and when one of the party killed the snake, it (that is, the bird) was found dead upon the spot—and that entirely from fear; for, on examination, it appeared not to have received the slightest wound. The same traveller adds that a short time afterwards he observed a small mouse in similar agonising convulsions, about two yards from a snake, whose eyes were intently fixed upon it; and on frightening away the reptile, and taking up the mouse, it expired in his hand." [1]

It is very probable that the several kinds of snakes circumvent their prey differently, and that their mode of doing so varies according to circumstances. This much seems certain: snakes exercise intelligence and strategy

[1] Thompson, "Passions of Animals," p. 118. Bingley, "Animal Biography," vol. ii., pp. 447, 448.

in seizing their food. They lie in wait, and place themselves in coigns of vantage as regards position, the colour of their surroundings, &c. They exercise reasoning powers in concealing themselves, in rearing their young, in catching their food, and in other ways. The fact that they can be readily tamed also bespeaks intelligence. Mr. W. Severn relates how friends of his (Mr. and Mrs. Mann and family) had in their house in London a tame boa-constrictor and several small snakes. These, when liberated, at once made themselves at home in the room, on furniture, writing-table, among books, &c. Mrs. Mann and children allowed the boa to coil itself round them, and called it by the most endearing names. The children took its head in their hands and kissed its mouth, pushing aside its forked tongue in doing so. The animal seemed much pleased at the attention bestowed upon it, and apparently expected to be petted like a kitten. The snakes were very obedient, and remained in their cupboard when told to do so. On one occasion Mr. and Mrs. Mann were necessarily absent from London for six weeks, and before leaving town deposited the box in the Zoological Gardens for safe keeping. "The poor reptile moped, slept, and refused to be comforted, but when his master and mistress appeared he sprang upon them with delight, coiling himself round them, and showing every symptom of intense delight." [1]

The end of the boa was tragic. Mr. Mann was seized with an apoplectic fit, and Mrs. Mann, hastening out to call a doctor, found, on her return, the snake stretched out beside him dead.

Mr. E. L. Layard relates a remarkable example of sagacity and reasoning power in a cobra which had thrust its head through a small aperture and swallowed a toad. "With this encumbrance he could not withdraw himself. Finding this, he reluctantly disgorged the precious morsel, which began to move off. This was too much for the snake philosophy to bear, and the toad was again seized; and again, after violent efforts to escape, was the snake compelled to part with it. This time, however, a lesson had been learnt, and the toad was seized by one leg, withdrawn, and then swallowed in triumph." [2]

Lord Monboddo relates a case of homing in a tame serpent which belonged to a Dr. Vigot of Madras. The reptile was taken by the French when they invested Madras, and carried by them in a close carriage to Pondicherry, a great way off. The reptile escaped, and after a time returned to its old master and old quarters, to the great surprise of every one.

Turtles during their migrations cover great distances. These animals are gifted with an extraordinary power of direction. Humboldt found that if newly hatched turtles were put in bags and carried considerable distances from the water, they would, when liberated, and when their heads were placed away from the water, invariably wheel round and make for it without the slightest hesitation. Frogs and toads, as explained, also possess this power. Crocodiles are similarly endowed.

Dr. Davy [3] mentions the case of a young crocodile which he cut out of the egg, and which, the moment it was liberated, made off in a straight line for a neighbouring stream.

Turtles exercise the extreme of caution in selecting places for depositing their eggs, and they perform this important function in a methodical manner. The turtles, according to Mr. Bates,[4] "excavate with their broad, webbed paws deep holes in the fine sand; the first comer, in each case, making a pit about three feet deep, laying its eggs (about 120 in number), and covering them with sand; the next making its deposit at the top of that of its predecessor, and so on until every pit is full. The whole body of turtles frequenting a praia does not finish laying in less than fourteen or fifteen days, even when there is no interruption. . . . The turtles lay their eggs by night, leaving the water, when nothing disturbs them, in vast crowds, and crawling to the central and highest part of the praia. These places are, of course, the last to go under water when, in unusually wet seasons, the river rises before the eggs are hatched by the heat of the sand. One could almost believe, from this, that the animals used forethought in choosing a place."

Tortoises are capable of being tamed, and of distinguishing between persons. The author of the "Natural History of Selborne" refers to a tortoise which, "whenever the good old lady came in sight, who had waited on it for more than thirty years, always hobbled with awkward alacrity towards its benefactress, whilst to strangers it was altogether inattentive."

Alligators can also be tamed. Thus Mr. Jesse narrates a case where a young alligator was domesticated and displayed great affection for a cat. This animal followed its master about the house like a dog, and when not so engaged, paid great attention to the cat, its chosen companion. If the cat were out of the way the alligator was restless; if it was present the alligator was happy, and generally fell asleep with its head resting on the cat. According to Mr. E. C. Buck,[5] the crocodiles of the Ganges sometimes fish in concert. He narrates a case where the crocodiles, which were lying on the bank and swimming in deep water, at a given signal arranged themselves in a double row across the mouth of a small stream, up which they swept, driving the fish before them and capturing several.

[1] *The Times*, July 25, 1872.
[2] *Annals and Magazine of Natural History*, 2nd series, vol. ix., p. 333.
[3] "Account of Ceylon."
[4] "Naturalist on the Amazon," pp. 285, 286.
[5] *Nature*, vol. viii., p. 303

§ 263. The Intelligence of Birds.

Birds are characterised by great activity and dash as compared with the cold-blooded animals. They also display a livelier and more robust intelligence. They exhibit many of the mental traits which characterise man. They remember and reason; they are curious, affectionate, emotional, proud, jealous and vindictive; they occasionally assume the rôle of freebooters; they fight and play; they judge each other; they are revengeful, resourceful, and adaptive; they are emulative and are even said to be æsthetical.

Their emotional nature is strongly developed. Their tender regard for their young is proverbial. They build nests, hatch out their young, provide them with food, teach them to fly, and, in some instances, to swim.

Their concern for their young is affecting, and, in many instances, evokes an admirable courage. Eagles defend their nests against all comers; barn-door fowls attack dogs and other animals if they approach their chicks, and larks will feed their young in a cage provided the nest be transferred thereto and the cage door left open. This I myself have seen. The gannet or solan goose is so tame while sitting on its eggs that it refuses to leave them on the approach of a stranger. On one occasion at the Bass Rock, Scotland, I poked the sitting birds with my stick, and got them to leave the eggs for a foot or two, but they immediately waddled back and made no attempt to fly away.

Birds are for the most part social. They congregate in flocks, and, to a large extent, live in common. They even establish colonies of nests, the nests being aggregated in certain localities like little villages. Birds live in communities, hence the well-known saying, "Birds of a feather flock together." These communities have their leaders or chiefs, to whom they yield obedience. Wild geese are conducted in their flights by old ganders.[1] Birds when feeding establish sentinels, which sound a note of warning when an enemy approaches; crows and other birds hold large meetings (virtually courts or parliaments), and dispense justice and punishment, protecting the weak, and chastising, and even killing, the aggressive and strong.

Bird life foreshadows that of the higher vertebrates, man included.

While birds are for the most part gregarious, they, not unfrequently, live apart or in pairs. The gregarious birds occasionally separate during the breeding season. In all cases the bird household is managed with much forethought, solicitude, and regularity. The idea of responsibility is never absent, and the parental cares are shared by both parents. Each parent, moreover, punctiliously discharges its share of duty. This is especially the case when birds are feeding their callow young. Under such circumstances, the parents toil at their task of food-bringing from early morn till dewy eve, nor once think of halting. The number of visits made to the nest in twenty-four hours in some cases exceeds two hundred.

In the bird community, as in the more exalted ones, there are harpies or birds of prey. These, as was to be expected, have larger heads and brains, and possess more intelligence than their fellows. They are likewise more daring and courageous. The hawk tribe practically knows no fear. Hawks descend on the fowl of the homestead, and even pursue their victims into the house and outhouses. Hawks, in many cases, display a high degree of intelligence. The kestrel has been known to follow closely express and other trains, taking advantage of the smoke and steam of the engine to conceal itself, and the opportunity afforded to it of pouncing upon the flocks of birds raised by the noise of the train.

Birds of prey are a great source of terror to smaller and weaker birds, which flock together and mob and hustle the despoilers. I saw, on one occasion, at Glenborrowdale Castle, Argyleshire, a sparrow-hawk mobbed and stupefied by the attack of a cloud of sparrows. I, on another occasion, witnessed a golden eagle which had perched on a cliff, pestered and persecuted by crows which kept darting down upon him at short intervals. The cliff emerged from a wood near the castle, and by the aid of a field-glass I could distinctly see everything that happened. I will not soon forget the fine scorn with which the noble bird regarded his assailants. The eye, head, and neck, the movements of which I could distinctly follow, were especially expressive of disgust. Latterly, the eagle threw himself

[1] I will never forget when on one occasion, at full moon at the end of the harvesting season, I went with my former colleague, Professor W. Knight (St. Andrews University), to shoot wild geese on the grain fields and moors extending between the villages of Leuchars and Tayport, Fifeshire. We concealed ourselves in a clump of trees and waited the arrival of the birds. The sky was full of them. One large flock wheeled round and round over our heads, and at last, to our great delight, commenced a spiral descent. When they were nearly within shot, the old gander in charge of the party suddenly emitted a loud, discordant note; he had perceived the hidden danger. Instantly, the descending column was converted into an ascending one, and in a few seconds the whole flock was again wheeling securely in mid air. It was very mortifying, but at the same time very edifying. When wild geese are wheeling about, or travelling, they give out a short, low, cackling note—a note of satisfaction, comfort, and security; and this runs through the whole flock uninterruptedly and continuously. If the birds are, from any cause, alarmed, the old gander leading utters his loud, discordant note and all the others are suddenly silent. On the night expedition referred to, I noticed that when the geese prepare to descend on an inviting spot they cease to emit the low, cackling note, and alight in dead silence. They also take wing in dead silence when disturbed. The low note is only resumed when they are well out of danger. My colleague and I unfortunately came home with empty bags, but we were richly rewarded by what we saw and heard in the weird moonlight. Anything finer than the concert given by wild sea-birds roosting on the margin of the estuary of the river Eden, on the return journey to St. Andrews, cannot possibly be imagined. The bark of the heron, the low caw of the cormorant, the melodious whistle of the curlew, the quack of the wild duck, the well-known sounds emitted by the gull, tern, redshank, plover, sandlark, &c., were all heard and enjoyed. Truly, nature when undisturbed is an enduring feast.

into the air, and by the aid of his powerful pinions wound himself majestically by ever-widening spiral circles into the blue ether, in which he ultimately disappeared.

Birds also rob each other; thus the skua gull pursues other gulls, and hustles and threatens them until they deliver up and disgorge their food. Gulls in turn rob the guillemots. If the latter find a shoal of fish and are feeding, the gulls hover over or settle on the water beside them. As soon as the guillemots catch fish the gulls filch it from them. The robber tern lives entirely by piracy and plunder. The white-headed eagle resorts to similar tactics with the osprey or fish-hawk. "When the latter rises from the water, with a fish in its grasp, forth rushes the eagle in pursuit. He mounts above the fish-hawk, and threatens it by actions well understood, when the latter, fearing that perhaps its life is in danger, drops its prey. In an instant the eagle, accurately estimating the rapid descent of the fish, closes its wings, follows it with the swiftness of thought, and the next moment grasps it. The prize is carried off in silence to the woods, and assists in feeding the ever hungry brood of the eagle."

The frigate pelican is a noted freebooter, and attacks and harasses the boobies until they drop their booty or actually disgorge the contents of their stomachs. The bullying and hustling to which the boobies are subjected are often severe and cruel; the pelican pecking its victims with its formidable beak until it effects its purpose.

Birds in feeding display considerable knowledge of the properties of matter and of physical laws. Thrushes carry shells containing snails to favourite stones, where they break them and gobble up their contents. Their mode of securing worms also bespeaks intelligence. When they seize the head of a worm projecting from the earth they do not attempt to drag the worm out forcibly. They simply put a strain on it, knowing that the worm, in order to relieve itself, will gradually disengage more and more of its body from the earth until it is at their mercy. The thrush will not run the risk of breaking the worm, and thus depriving itself of any part of the coveted morsel. This process of worm extraction I have repeatedly watched.

The pee-wit stamps with its foot on the ground where there is a worm cast, and frightens the worm and causes it to emerge. It also follows burrowing moles and seizes the worms, as they endeavour to escape from their four-legged enemies. Gulls habitually follow the plough in anticipation of the rich repasts which it throws up. This is an every-day occurrence during the ploughing season at St. Andrews and in Fifeshire generally.

Sea and other birds are in the habit of flying up considerable distances with shell-fish in their bills, which they drop on rocks to break the shells and free the juicy morsels.

The late Dr. Fleming, Professor of Natural History in the Free Church College, Edinburgh, informed me that on one occasion he saw near Prestonpans, a seaside suburb of Edinburgh, a crow take up several shell-fish in succession, which, being dropped on the rocks and the shells broken, were in due course transferred to the crop of the bird. While this process of shell breaking and feeding was going on, a second crow appeared and perched on a rock near the scene of action. The second crow permitted the first to fly up and drop and break the shell, but darted in and secured the prize before the first crow could descend to the rock. This manœuvre was repeated, when the first crow flew away, apparently disgusted. Dr. Fleming came to the conclusion that the first crow was a young one; the second being an older and more experienced bird.

It is scarcely necessary to state that birds, when they break shells by their beaks, know what they are about; that the flying up with, and dropping and breaking shells on hard substances beneath, bespeaks a considerable amount of knowledge, and that the bird which permits another bird to fly up with, and drop and break a shell for it, and so avails itself of its labour, possesses quite a remarkable degree of knowledge. The simpler and more complicated acts indicate a graduated intelligence. These acts afford examples of pure reason.

The naturalist, Mr. Tom Edward, whose life has been so felicitously written by Dr. Smiles, thus describes the doings of the carrier and hooded crow: "He goes aloft with a crab, and lets it fall upon a stone or a rock chosen for the purpose. If it does not break he seizes it again, goes up higher, lets it fall, and repeats his operation again and again until his object is accomplished. When a convenient stone is once met with, the birds resort to it for a long time. I myself know a pretty high rock, that has been used by successive generations of crows for about twenty years!" Also, as Handcock says, "a friend of Dr. Darwin saw on the north coast of Ireland above a hundred crows preying upon mussels, which are not their natural food; each crow took a mussel into the air, twenty or forty yards high, and let it fall on the stones, and thus breaking the shell got possession of the animal. Ravens, we are told, often resort to the same contrivance."

Mr. Tom Edward gives a good example of reasoning power in the turnstone. This bird, as its name indicates, obtains its food by turning over stones, bits of wood, dead fish, &c., on the shore; the displaced substances generally displaying a rich harvest of worms, grubs, and other living things. On the particular occasion referred to, two turnstones were attempting to turn over a stranded cod-fish 3½ feet in length, embedded in the sand. Mr. Edward thus narrates the circumstance:[1] "Having got fairly settled down in my pebbly observatory, I turned

[1] Smiles, "Life of a Scotch Naturalist," pp. 244-46.

my undivided attention to the birds before me. They were boldly pushing at the fish with their bills, and then with their breasts. Their endeavours, however, were in vain ; the object remained immovable. On this they both went round to the opposite side and began to scrape away the sand from beneath the fish. After removing a considerable quantity, they again came back to the spot which they had left, and went once more to work with their bills and breasts, but with as little apparent success as formerly. Nothing daunted, however, they ran round a second time to the other side, and recommenced their trenching operations with a seeming determination not to be baffled in their object, which evidently was to undermine the dead animal before them, in order that it might be the more easily overturned. While they were thus employed, and after they had laboured in this manner at both sides alternately for nearly half-an-hour, they were joined by another of their own species, which came flying with rapidity from the neighbouring rocks. Its timely arrival was hailed with evident signs of joy. I was led to this conclusion from the gestures which they exhibited, and from a low but pleasant murmuring noise to which they gave utterance so soon as the new-comer made his appearance. Of their feelings he seemed to be perfectly aware, and he made his reply to them in a similar strain. Their mutual congratulations being over, they all three set to work ; and after labouring vigorously for a few minutes in removing the sand, they came round to the other side, and putting their breasts simultaneously to the fish, they succeeded in raising it some inches from the sand, but were unable to turn it over. It went down again into its sandy bed, to the manifest disappointment of the three. Resting, however, for a space, and without leaving their respective positions, which were a little apart the one from the other, they resolved, it appears, to give the work another trial. Lowering themselves, with their breasts pressed close to the sand, they managed to push their bills underneath the fish, which they made to rise about the same height as before. Afterwards, withdrawing their bills, but without losing the advantage which they had gained, they applied their breasts to the object. This they did with such force, and to such purpose, that at length it went over, and rolled several yards down a slight declivity. It was followed to some distance by the birds themselves before they could recover their bearings."

One of the best examples known of affection and reasoning in birds is also given by Mr. Edward. On one occasion he shot and winged a tern, which fell into the sea and was drifting towards him. The following are his words : " While matters were in this position I beheld, to my utter astonishment and surprise, two of the unwounded terns take hold of their disabled comrade, one at each wing, lift him out of the water, and bear him out seawards. They were followed by two other birds. After being carried about six or seven yards, he was let gently down again, when he was taken up in a similar manner by the two who had been hitherto inactive. In this way they continued to carry him alternately, until they had conveyed him to a rock at a considerable distance, upon which they landed him in safety. Having recovered my self-possession, I made toward the rock, wishing to obtain the prize which had been so unceremoniously snatched from my grasp. I was observed, however, by the terns ; and instead of four, I had in a short time a whole swarm about me. On my near approach to the rock I once more beheld two of them take hold of the wounded bird as they had done already, and bear him out to sea in triumph far beyond my reach. This, had I been so inclined, I could no doubt have prevented. Under the circumstances, however, my feelings would not permit me ; and I willingly allowed them to perform without molestation an act of mercy, and to exhibit an instance of affection which man himself need not be ashamed to imitate." [1]

According to Clavigero [2] the Mexicans trade upon the sympathies of wild pelicans for obtaining supplies of fresh fish. Their mode of procedure is effective but cruel. They secure a wild pelican, break one of its wings, and tie it to some fixed object. The mates of the wild pelican flock round the wounded captive bird, and seeing it in pain and without food, they unload their pouches and crops of the large quantities of fish which they contain. Only a small portion of fish is set apart for the tethered pelican. All the rest is eagerly appropriated by the unfeeling strategists.

Tame cormorants are treated in a somewhat similar way by the Chinese and other semi-barbarous peoples. The cormorants have a strap of leather firmly fastened round their throats to prevent their swallowing the fish they catch. Thus muzzled, they are taken to the sea, rivers, and lakes in a boat and encouraged to fish. They dart after and seize their finny prey with great alacrity, and bring it to their masters, who collect and stow it away.

As examples of sympathy and affection in birds the following may be cited : " A pair of swans had been inseparable companions for three years, during which time they had reared three broods of cygnets ; last autumn the male was killed, and since that time the female has separated herself from all society with her own species ; and, though at the time I am writing (the end of March), the breeding season for swans has far advanced, she remains in the same state of seclusion, resisting the addresses of a male swan, who has been making advances towards forming an acquaintance with her, either driving him away, or flying from him whenever he comes near her. How long she will continue in this state of widowhood I know not, but at present it is quite evident that she has not forgotten her former partner."

[1] "Life of a Scotch Naturalist," by Dr. Smiles, p. 240.

[2] "History of Mexico," p. 220.

Similarly, a hen pigeon bewailed her lord and master. A man set to watch a field of peas at Chalk Farm, near Hampton, shot an old cock pigeon. "His mate, around whom he had for many a year cooed, whom he had nourished from his own crop, and had assisted in rearing numerous young broods, immediately settled on the ground by his side, and showed her grief in the most expressive manner. The labourer took up the dead bird, and tied it to a short stake, thinking that it would frighten away other depredators. In this situation, however, the widow did not forsake her dead husband, but continued, day after day, walking slowly round the stick. The kind-hearted wife of the bailiff of the farm at last heard of the circumstance, and immediately went to afford what relief she could to the poor bird. She told me that, on arriving at the spot, she found the hen bird much exhausted, and that she had made a circular beaten track round the dead pigeon, making now and then a little spring towards him. On the removal of the dead bird the hen returned to the dovecot." [1]

In the Rotund of the Jardin des Plantes in Paris, a male ostrich was unfortunate enough to lose its mate. It moped, sickened, and died not long afterwards.

Mr. Bennet relates a case of the fidelity of ducks. The drake was stolen by thieves, and the duck became inconsolable, and retired into a corner and neglected her food and drink as well as the care of her person. "In this condition she was courted by a drake who had lost his mate, but who met with no encouragement from the widow. On the stolen drake being subsequently recovered and restored to the aviary, the most extravagant demonstrations of joy were displayed by the fond couple; but this was not all, for, as if informed by his spouse of the gallant proposals made to her shortly before his arrival, the drake attacked the luckless bird who would have supplanted him, beat out his eyes, and inflicted so many injuries as to cause his death." [2]

Mr. Romanes gives the following from a lady correspondent: "My grandfather had a Swan River gander, which had been reared near the house, and had consequently attached himself to the members of the family; so much so that, on seeing any of them at a distance, he would run to meet them with all possible demonstrations of delight. But Swanny was quite an outcast from his own tribe; and as often as he made humble overtures to the other geese, so often was he driven away with great contempt, and on such occasions he would frequently run to some of his human friends, and laying his head on their laps, seem to seek for sympathy. At last, however, he found a friend among his own species. An old grey goose, becoming blind, was also discarded by her more fortunate companions, and Swanny lost no opportunity of recognising this comrade in distress. He at once took her under his protection and led her about. When he considered it well for her to have a swim, he would gently take her neck in his bill, and thus lead her, sometimes a considerable distance, to the water's edge. Having fairly launched her, he kept close by her side, and guided her from dangerous places by arching his neck over hers, and so turning her in the right direction. After cruising about a sufficient time, he would guide her to a convenient landing-place, and taking her neck in his bill as before, lead her to *terra firma* again. When she had goslings, he would proudly convoy the whole party to the water-side; and if any ill-fated gosling got into difficulties in a hole or deep cart-rut, Swanny, with ready skill, would put his bill under its body, and carefully raise it to the level ground." [3]

Dr. Franklin narrates how a male parrot tended and assisted in various ways an invalid female parrot. "His constancy, his gestures, and his continued solicitude, all showed in this affectionate bird the most ardent desire to relieve the sufferings and assist the weakness of his companion.

"But the scene became still more interesting when the female was dying. Her unhappy spouse moved round her incessantly, his attention and tender cares redoubled. He even tried to open her beak to give some nourishment. He ran to her, then returned with a troubled and agitated look. At intervals he uttered the most plaintive cries; then, with his eyes fixed on her, kept a mournful silence. At length his companion breathed her last; from that moment he pined away, and died in the course of a few weeks." [4]

Birds possess considerable powers of observation. Rooks, for example, are exceedingly suspicious of any one carrying a gun or anything resembling a gun. They can also distinguish Sundays from ordinary days, and are particularly tame on the former. If one of them is shot, and wounded or killed, its associates fly about in a distressed manner, plainly proving that they fully realise that something is wrong. The same holds true of sea-gulls, which on such occasions frequently come quite close to the fowlers, and themselves become victims. This I have myself frequently witnessed on the west coast of Scotland.

Birds even anticipate and avoid danger. On one occasion, at the Manor House, Chislehurst, England, my wife observed a cat stalking a blackbird on the lawn. A passing swallow in full flight, perceiving what was going on, swooped down and brushed the head of the cat from behind, with the result that pussy was completely outwitted and terrified, and beat a hasty retreat.

Some birds remember as well as reason. A friend of mine who has a house, large garden, and fine old trees

[1] "Gleanings," vol. i., pp. 112, 113.
[2] Couch, "Illustrations of Instinct," p. 165.
[3] "Animal Intelligence," International Scientific Series, 7th edition, 1898, pp. 272, 273.
[4] "Zoologist," vol. ii.

at Hampstead, London, told me of occasional visits paid him by a tame raven. This bird, which presented a grave, dignified appearance, was fond of the remains of a chop or steak, or meat of any sort, and this was regularly provided for it. On one occasion the supply exceeded the demand, and the raven scraped a hole in the soil and buried the remainder of its meal. It then flew off quite jauntily and in high spirits. Next day it returned and at once made for the buried food, which it forthwith exhumed. This was remarkable, but what followed was still more so. The food was soiled by its contact with the earth, and the raven, perceiving this, snatched it up hastily and flew with it to a fountain in the garden, where it carefully washed it prior to devouring it. This case requires no comment.

As examples of memory in birds, the so-called talking and whistling birds may be cited. Parrots, starlings, &c., as is well known, can be taught to speak sentences and to whistle tunes. They acquire their vocabulary and their notes by tedious efforts and repetitions, and by remembering and imitating as children do. My father, who was particularly fond of birds, had generally a parrot and a starling as pets. He was very patient and painstaking in teaching them. He was a splendid whistler, and his pets were adepts in this direction. He gave his lessons after 10 o'clock P.M., when the house was perfectly quiet, and the attention of the birds was not distracted by extraneous sounds. It was very interesting and instructive to observe how very attentive and anxious the birds were to learn. They turned their heads in the direction of whatever sound he made, and attempted to imitate and repeat it. They sooner or later succeeded. The starling could whistle the first part of "O'er the water to Charlie," and the parrot (a grey one) could whistle almost as well as its master. It was particularly successful in every form of dog call, and on occasions kept the dogs, of which we always had several, running all over the house. It especially victimised an old collie dog, which was so often tricked that latterly it was next to impossible to get him to stir by any amount of human whistling. The parrot seemed to take a real delight in producing stampedes of the dogs, and nothing could possibly be more amusing. The starling could utter a few words very plainly, and whistled very sweetly and correctly. The parrot was more or less a master in language, and his ability to whistle was unequalled.

Many interesting anecdotes are told of parrots. According to Dr. Samuel Wilks, parrots learn their lessons in the same way as children do, and their speaking is due to suggestion and association—"the usual provocative for set speeches at all periods of human life."

Dr. Wilks thus writes of his own parrot:[1] "In beginning to teach the parrot a sentence, it has to be repeated many times, the bird all the while listening most attentively by turning the opening of the ear as close as possible to the speaker. After a few hours it is heard attempting to say the phrase, or, I should say, trying to learn it. It evidently has the phrase somewhere in store, for eventually this is uttered perfectly, but at first the attempts are very poor and ludicrous. If the sentence be composed of a few words, the first two or three are said over and over again, and then another and another word added, until the sentence is complete, the pronunciation at first being very imperfect, and then becoming gradually more complete, until the task is accomplished. Thus hour after hour will the bird be indefatigably working at the sentence, and not until some days have elapsed will it be perfect. . . . Then the mode of forgetting, or the way in which phrases and airs pass from its recollection, may be worth remarking. The last words or notes are first forgotten, so that soon the sentence remains unfinished or the air only half whistled through. The first words are the best fixed in the memory; these suggest others which stand next to them, and so on till the last, which have the least hold on the brain. These, however, can be easily revived on repetition. . . . In trying to recall poems learned in childhood or in school days, although at that period hundreds of lines may have been known, it is found that in manhood we remember only the two or three first lines of the 'Iliad,' the 'Æneid,' or the 'Paradise Lost.'"

Parrots are in many instances sportive and mischievous. On one occasion a parrot and a cat fell out. The parrot a short time after called out in most persuasive tones, "Puss, puss, come then—come then, pussy." The cat approached confidingly, when Polly tipped a basin of milk over her and chuckled hilariously.

Lady Napier relates the following anecdote of a grey parrot: "Sometimes when only two or three were in the room, at quiet occupations instead of talking, she would utter at short intervals a series of strong squalls or cries in an interjectional style, each more strange and grotesque than the previous one. My father on these occasions sometimes amused himself by imitating these cries as she uttered them, which seemed to excite her ingenuity in the production of them to the uttermost. As a last resource she always had recourse to a very peculiar one, which completely baffled him; upon which, with a loud 'ha! ha! ha!' she made a summersault round her perch, swinging with her head downwards, sprung from one part of the cage to another, and tossed a bit of wood she used as a toy over her head in the most exulting triumph, repeating at intervals the inimitable cry, followed by peals of 'ha! ha! ha!' to the great amusement of all present."

[1] *Journal of Medical Science*, July 1879.

According to Mr. Margrave, parrots sometimes dream and talk in their sleep as men do—the psychological processes in both cases being the same.

My father, always an enthusiastic admirer of animals, did not confine his attention to parrots and starlings. At our home in Lanarkshire, Scotland, we had many other birds, and quite a large assortment of pet animals. Our outhouses and attics were in a way miniature menageries. We had a fox, rabbits, a squirrel, ferrets, in addition to bigger domestic stock, and the aviary embraced the finer kinds of pigeons, an owl, a magpie, a jackdaw, a pair of brown grouse, &c. The grouse were kept apart in a large attic, where they had room to run about and even to fly. During the season this was supplied every day with fresh heather, and so little did they resent their confinement, and so tame were they, that they actually bred; the hen laying twelve eggs, on which she sat with dogged perseverance. During the hatching process the cock grouse was so jealous and bold that he flew at the head of any stranger who was injudicious enough to pop his head through the trap door of the attic intent on witnessing the unexampled phenomenon of a hen-grouse sitting on eggs in captivity. The birds were strong and in splendid plumage, and it looked as if the young grouse would be successfully hatched out. Unfortunately the cock grouse was killed by a weasel which somehow had found its way into the attic. The hen grouse thereupon left her nest and eggs, to which she never returned. She became restless, uneasy, moped, and ultimately died. This little tragedy illustrates very well the valour, constancy, and affection of birds.

Birds in many cases display great powers of rivalry. This is seen in the spring, or courting time, when the song-birds emulate each other in the vigour and sweetness of their songs and in the display of gaudy plumage. The blackbirds, thrushes, and larks pour forth a very flood of melody, and the strutting of the turkey-cock and peacock with outspread tails and lowered wings symbolises the pride they have in finery. At the breeding season the males not unfrequently do battle for the females after the manner of the old knights in the tournament. These battles are, in many cases, pitched battles, the hen birds forming the spectators. Speaking of battles, I witnessed recently (1905) in the grounds of the palace of Schoenbrunn, Vienna, where the Emperor of Austria has a small zoological collection, a most determined fight between two young turkey cocks. This is not an unusual occurrence, but what did surprise me was the vigorous attempt made by two fine full-grown peacocks to separate the combatants. Again and again one or other of the peacocks flew at and between the assailants, and with its wings, legs, and feet forcibly made them desist. As the turkey cocks renewed their strife, so the peacocks renewed their praiseworthy efforts at peace-making. The war raged for nearly a quarter of an hour, and during that period the magnanimous peacocks interposed at least eight times. At last one of the turkey cocks gave in, and fled ignominiously from the well-contested field. The fight attracted quite a large number of interested spectators, of whom none were more amused and instructed than I myself.

Birds are in some instances savage and highly vindictive. This is especially true of storks, as the following narrative shows: "In the college yard at Tübingen there lived a tame stork, and in a neighbouring house was a nest, in which other storks, that annually resorted to the place, used to hatch their eggs. At this nest, one day in autumn, a young collegian fired a shot, by which the stork that was sitting on it was probably wounded, for it did not fly out of the nest for some weeks afterwards. It was able, however, to take its departure at the usual time with the rest of the storks. But in the ensuing spring a strange stork was observed on the roof of the college, which, by clapping his wings and other gestures, seemed to invite the tame stork to come to him; but, as the tame one's wings were clipped, he was unable to accept the invitation. After some days the strange stork appeared again, and came down into the yard, when the tame one went out to meet him, clapping his wings as if to bid him welcome, but was suddenly attacked by the visitor with great fury. Some of the neighbours protected the tame bird, and drove off the assailant, but he returned several times afterwards, and incommoded the other through the whole summer. The next spring, instead of one stork only, four storks came together into the yard, and fell upon the tame one, when all the poultry present—cocks, hens, geese, and ducks—flocked at once to his assistance, and rescued him from his enemies. In consequence of this serious attack, the people of the house took precautions for the tame stork's security, and he was no more molested that year. But in the beginning of the third spring came upwards of twenty storks, which rushed at once into the yard and killed the tame stork before either man or any other animal could afford his protection.

"A similar occurrence took place on the premises of a farmer near Hamburg, who kept a tame stork, and, having caught another, thought to make it a companion for the one in his possession. But the two were no sooner brought together than the tame one fell upon the other, and beat him so severely that he made his escape from the place. About four months afterwards, however, the defeated stork returned with three others, who all made a combined attack upon the tame one and killed him." [1]

Birds not only fight, they also play. The playful faculty is well seen in the bower birds. The following

[1] "Reasoning Power of Animals," by Watson, pp. 375, 376.

is the description given by Mr. Gould: "The extraordinary bower-like structure, alluded to in my remarks on the genus, first came under my notice in the Sydney Museum, to which an example had been presented by Charles Cox, Esq. . . . On visiting the cedar bushes of the Liverpool range, I discovered several of these bowers or playing-houses on the ground, under the shelter of the branches of the overhanging trees in the most retired part of the forest; they differed considerably in size, some being a third larger than others. The base consists of an extensive and rather convex platform of sticks firmly interwoven, on the centre of which the bower itself is built. This, like the platform on which it is placed, and with which it is interwoven, is formed of sticks and twigs, but of a more slender and flexible description, the tips of the twigs being so arranged as to curve inwards and nearly meet at the top; in the interior the materials are so placed that the forks of the twigs are always presented outwards, by which arrangement not the slightest obstruction is offered to the passage of the birds. The interest of this curious bower is much enhanced by the manner in which it is decorated with the most gaily coloured articles that can be collected, such as the blue tail-feathers of the rose-bill and pennantian parakeets, bleached bones and shells of snails, &c.; some of the feathers are inserted among the twigs, while others, with the bones and shells, are strewed near the entrances. The propensity of these birds to fly off with any attractive object is so well known to the natives that they always search the runs for any small missing article that may have been accidentally dropped in the bush. I myself found at the entrance of one of them a small neatly worked stone tomahawk, of an inch and a half in length, together with some slips of blue cotton rag, which the birds had doubtless picked up at a deserted encampment of the natives."

Mr. Herbert Spencer is of opinion that the artistic feelings are physiologically allied with those of play, and some affect to believe that birds display an æsthetic sense.

Birds are naturally curious. They will come long distances to examine a strange object. In uninhabited countries they have been known to approach travellers and scrutinise them at close quarters without any fear or misgiving.

The migrations of birds at certain seasons are very remarkable. On such occasions they fly very high, and travel long distances, mostly at night. Their flights are determined for the most part by cold and the food supply. Usually they fly from colder to warmer regions, where the conditions of life are easier. The migrations are difficult to explain. They are unerringly accomplished without chart or compass, and the departure and arrival of migratory birds can be calculated almost to a day. They are ascribed to instinct, which in this as in most other cases means nothing. The most likely solution is that they are performed under the guidance of old leaders, which have derived their knowledge of the several routes from their immediate progenitors. Originally, no doubt, the leaders obtained their knowledge of direction from landmarks before the continents were broken up and the great seas formed. Animals, as has been already shown, have certainly a faculty of direction, and this seems to be greatly developed in the case of migratory birds. That birds are provided with long vision, and can fly at great heights and for long distances, is proved by the condors. The condor of the Andes attains an altitude of seven miles, and an animal killed in the open by man or beast immediately attracts vultures in numbers, although not a bird was to be seen in the sky at the time. The gathering of the birds to the carrion is due not to the sense of smell but to that of sight. It suffices if one vulture witnesses the death; he flies in the direction of the quarry and gives a lead to others, which follow in succession for miles.

Birds in many cases display great ingenuity in attaining their ends. This is especially true of the crow tribe, which are notorious at once for their cleverness and predacious habits. Sir E. Tennent, in his "Natural History of Ceylon," thus speaks of the crows of that island: "One of these ingenious marauders, after vainly attitudinising in front of a chained watch-dog, that was lazily gnawing a bone, and after fruitlessly endeavouring to divert his attention by dancing before him, with head awry and eye askance, at length flew away for a moment, and returned bringing a companion, which perched itself on a branch a few yards in the rear. The crow's grimaces were now actively renewed, but with no better success, till its confederate, poising itself on its wings, descended with the utmost velocity, striking the dog upon the spine with all the force of its strong beak. The *ruse* was successful; the dog started with surprise and pain, but not quickly enough to seize his assailant, whilst the bone he had been gnawing was snatched away by the first crow the instant his head was turned. Two well-authenticated instances of the recurrence of this device came within my knowledge at Colombo, and attest the sagacity and powers of communication and combination possessed by these astute and courageous birds."

Miss Bird gives a similar account of the crows in Japan.[1] She writes: "In the inn garden I saw a dog eating a piece of carrion in the presence of several of these covetous birds. They evidently said a great deal to each other on the subject, and now and then one or two of them tried to pull the meat away from him, which he resented. At last a big, strong crow succeeded in tearing off a piece, with which he returned to the pine where the others

[1] "Unbeaten Tracks in Japan," vol. ii., pp. 149, 150.

were congregated, and after much earnest speech they all surrounded the dog, and the leading bird dexterously dropped the small piece of meat within reach of his mouth, when he immediately snapped at it, letting go the big piece unwisely for a second, on which two of the crows flew away with it to the pine, and with much fluttering and hilarity, they all ate, or rather gorged it, the deceived dog looking vacant and bewildered for a moment, after which he sat under the tree and barked at them inanely." She continues: "A gentleman told me that he saw a dog holding a piece of meat in like manner in the presence of three crows, which also vainly tried to tear it from him, and after a consultation they separated, two going as near as they dared to the meat, while the third gave the tail a bite, sharp enough to make the dog turn round with a squeak, on which the other villains seized the meat, and the three fed triumphantly upon it on the top of a wall."

The crows can certainly be credited with a large amount of intelligence, and, under this head, I include memory, judgment, and morality of a kind. Evidence has already been given of their power to remember and reason, and there are well-marked instances where the crows have held meetings or parliaments to examine, judge, and punish offenders.

A common offence among crows is filching from each others' nests during the nesting season. This I myself have again and again witnessed. In these cases, certain crows in the rookery watch the nests of the others, and rob them of their building material when the rightful owners are absent. On such occasions it not unfrequently happens that ten or a dozen rooks assemble and tear the nests of the offenders to pieces. Other and graver offences are visited with condign punishment, and even death. For the weightier offences, regular "crow courts or parliaments" are held and capital punishment inflicted. Dr. Edmondston informs us that in Shetland the *Corvus cornix*, a crow allied to the rook, at times assembles in great numbers from all points of the compass on a particular hill or field, and that the business to be conducted at these meetings is delayed for a day or two "till, all the deputies having arrived, a general clamour or croaking ensues, and the whole of the court, judges, barristers, ushers, audience, and all, fall upon two or three prisoners at the bar, and beat them till they kill them. When this is accomplished the court breaks up and quietly disperses." [1] Dr. Edmondston continues: "In the northern parts of Scotland and in the Faroe Islands extraordinary meetings of crows are occasionally known to occur. They collect in great numbers, as if they had all been summoned for the occasion; a few of the flock sit with drooping heads, and others seem as grave as judges, while others again are exceedingly active and noisy; in the course of about one hour they disperse, and it is not uncommon, after they have flown away, to find one or two left dead on the spot. These meetings will sometimes continue for a day or two before the object, whatever it may be, is completed. Crows continue to arrive from all quarters during the session. As soon as they have all arrived, a very general noise ensues; and, shortly after, the whole fall upon one or two individuals, and put them to death. When the execution has been performed, they quietly disperse."

Major-General Sir George Le Grand Jacob gives an account of similar meetings of crows in India. He remarks that while sitting in a verandah in India he saw three or four crows perch on a neighbouring house. They at once began to caw very vigorously and in a peculiar fashion. "Soon a gathering of crows from all quarters took place, until the roof of the guard-house was blackened by them. Thereupon a prodigious clatter ensued; it was plain that a 'palaver' was going forward. Some of its members, more eager than others, skipping about, I became interested, and narrowly watched the proceedings, all within a dozen yards of me. After much cawing and clamour, the whole group suddenly rose into the air, and kept circling round half-a-dozen of their fellows, one of whom had been clearly told off for punishment, for the five repeatedly attacked him in quick succession, allowing no opportunity for their victim to escape, which he was trying to do, until they had cast him fluttering on the ground about thirty yards from my chair."

The history and practice of falconry is a record of bird intelligence. The hawks are taught to perch on the hand, and when in the field each hawk has its head covered with a hood. The hood is taken off when the quarry is flushed. The unhooding is the signal for the hawk to take wing, and this it does very promptly and to good purpose. Pigeons, woodcock, partridges, grouse, wild duck, herons, and other birds are thus successfully hunted. The hawks, which have frequently little silver bells attached to their legs, to indicate their whereabouts, return when their flight is over to the head falconer or are lured back by him. That hawks can be trained to hunt speaks volumes for their intelligence. Only animals possessing intelligence can be trained. It is important to state in this connection that hawks, and birds of prey generally, have larger brains than the birds which they pursue, seize, and devour. The same is true of the carnivora among animals. Similar remarks are to be made of wild and tame animals. Wild animals have to seek their food and forage for themselves; tame animals, on the contrary, have their food provided for them; wild animals are obliged to exercise their brains in the mere effort of living; tame ones, in a sense, live mechanically. Scheming and thinking quicken the wits, and augment the quantity of brain substance.

[1] "View of the Shetland Islands."

What is said of hunting hawks applies equally to homing or carrier pigeons. These birds by careful training have been taught to fly immense distances, and to carry important written messages. The birds are taken away from their dovecots by degrees, and always allowed to fly back to them. Their flights are at first short—half a mile or a mile; they are gradually increased till the distance covered is fifty or even a hundred or more miles. When the pigeon is liberated for its home flight it generally makes two or three wide circles in mid air, and, having ascertained its bearings, it makes straight for its dovecot. There is little doubt that the bird has its land and other marks just as the bee has, and that its homing faculty is largely traceable to a combination of intelligence, memory, and judgment. The rapidity of the flight of the pigeon on such occasions is often phenomenal; as many as eighty miles being covered in an hour. How a bird can be taught to take such long journeys is a source of wonder and astonishment to the uninitiated. These long flights are equalled and greatly excelled by the voluntary flights of countless birds during the migratory period. At this particular season the birds collect in great numbers, and, at a concerted signal, take wing. They usually fly at night and at a great altitude. These conditions make their long flights more or less unintelligible, as land and other marks (the celestial bodies excepted) are, under the circumstances, of practically little avail. The sense of direction in birds, as in many other animals, is a veritable pole star which never deceives them. Their journeys are to be reckoned by hundreds and even thousands of miles. They fly from colder to warmer climates, and conversely, partly in search of food, and partly for the purposes of nidification. They also seek and derive benefit from change. This desire for change they share with several other animals—man included.

Not the least remarkable feature among birds is their nidification or power of building nests. This they possess in common with the ant, bee, wasp, certain fishes, and not a few animals.

The nests of birds display a very varied architecture; some being very simple, and others highly complex. As a matter of fact, some birds do not build nests at all, but lay their eggs on rocks or on the ground, or in holes dug in the ground by themselves, or by rabbits, and other animals. The sand-martins and sheldrakes lay their eggs in holes. Many of the sea-birds, such as the gulls, terns, gannets, razor-bills, guillemots, and penguins, lay their eggs on the ledges of rocks or on sand slightly scooped out. The eggs are fully exposed and there is no nest proper. In other cases, as in the grebe, water-hen, and bald coot, a few straws, sedges, or twigs are artlessly heaped together; the nest being flat and shapeless. In others, again, as in crows, magpies, and birds of prey, a large, loose, cumbrous nest of twigs and branches is made. It is in the song and smaller birds, more especially, such as the blackbird, thrush, lark, chaffinch, hedge-sparrow, wren, robin, &c., that bird architecture receives its fullest development. In these nests the design and the materials are equally deserving of commendation. As a boy nothing in the world gave me greater pleasure than to go bird-nesting. The feast of Alexander was nothing to it. My chief delight, as a youth, was to scamper across the Lanarkshire moors in the spring, when the blackcock, grouse, curlews, peewits, and other birds were pairing and nesting. If I could entice one of the setters to go with me, the enjoyment was perfect. The whir-whir of the birds and the splutter of their wings made my hair stand and the blood tingle to my finger-points. The defiant notes of the blackcock and grouse when disturbed, and the wild cries above and around me, fairly captivated my young imagination. I was often reprimanded for my marauding habits, as it was considered almost a crime to encroach on the game preserves at the particular season referred to. But boys will be boys. I could not resist the temptation to see nature in her seclusion at the nuptial period; and to watch the dog working and pointing in the heather, fairly carried me out of myself. The excitement, and the keen fresh breezes laden with the most delicate perfumes, made me feel as if I were treading on air. On such occasions I was frequently deceived by the strategy of the peewit (green plover or lapwing). That most beautiful bird is, at the nesting season, a consummate actor. When I approached its nest, it uttered a plaintive, distressed cry, and displayed, what appeared to me, a broken wing (hence lapwing). It took short irregular flights, and I felt convinced the bird was wounded. In my simplicity and enthusiasm I followed the cunning deceiver far afield. When it got me to a safe distance from its nest it extended its quasi-broken wing and flew aloft in ever-widening circles, uttering as it did so the jubilant note which announces victory. Here was intelligence and strategy of the first order. Many other animals besides birds feign injury, and even death, in presence of an enemy.

The nests of particular species of birds greatly resemble each other, but they are never identical either as regards their shape or the material employed in their construction. Birds are quick to perceive advantages, and select and appropriate different materials under different circumstances. The shape of the bird is no criterion of the shape of the nest; all birds much resemble each other in form, but the configuration of nests varies infinitely. The swallows are experts in nest-building, as they lay a regular foundation, and build in the angles of windows and other parts, which renders the process exceedingly difficult. They also build with wet, plastic material, one part of which must harden and dry before fresh material can be added. Certain of the swifts supply their own building material

in the shape of a viscid salivary secretion. This, when it dries, resembles isinglass, and forms the "edible birds' nests" so much prized by Chinese epicures.

Great ingenuity, perseverance, and adaptive skill are required in some cases. Jackdaws have been known to build in old windows, loopholes, and openings in ruined, disused staircases, with the result that the twigs employed in construction kept falling away. Nothing daunted, the birds persevered until they secured a foundation on the stair itself, and, so to speak, under-pinned their nest by erecting what was virtually a huge buttress which was out of all proportion to the nest itself. The birds had sagacity enough to perceive that, in order to complete the superstructure, they must provide a substantial foundation, and this they did at enormous cost of material and labour.

Nests, as a rule, are detached, solitary, and concealed. There are, however, cases where a large assemblage of nests are found under one and the same roof. The nest of the sociable grosbeak of Africa affords an example of the compound nest. The following is the account given of it by Le Vaillant.[1] He writes : "I observed on the way a tree with an enormous nest of these birds, which I have called republicans ; and as soon as I arrived at my camp I dispatched a few men with a waggon to bring it to me, that I might open and examine it. When it arrived, I cut it in pieces with a hatchet, and saw that the chief portion of the structure consisted of a mass of Boshman's grass, without any mixture, but so compact and firmly basketed together as to be impenetrable to the rain. This is the commencement of the structure, and each bird builds its particular nest under this canopy. But the nests are formed only beneath the eaves, the upper surface remaining void, without, however, being useless ; for as it has a projecting rim, and is a little inclined, it serves to let the water run off, and preserves each little dwelling from the rain. Figure to yourself a huge irregular sloping roof, all the eaves of which are covered with nests, crowded one against another, and you will have a tolerably accurate idea of these singular edifices. Each individual nest is three or four inches in diameter, which is sufficient for the bird ; but, as they are all in contact with one another around the eaves, they appear to the eye to form but one building, and are distinguishable from each other by a little external aperture which serves as an entrance to the nest ; and even this is sometimes common to three different nests, one of which is situated at the bottom and the other two at the sides. This large nest, which was one of the most considerable I had anywhere seen in the course of my journey, contained 320 inhabited cells, which, supposing a male and female to each, would form a society of 640 individuals ; but as these birds are polygamous, such a calculation would not be exact."

Many curious anecdotes are related of nidification. The house-martin constructs its nest of clay, into which it has worked little bits of straw, splinters of wood, &c., to make it stronger. Mr. Gilbert White points out that the house-martins carry forward their work not continuously but at stated, time-regulated intervals. "That this work may not, while it is soft and green, pull itself down by its own weight, the provident architect has prudence and forbearance enough not to advance her work too fast ; but by building only in the morning, and by dedicating the rest of the day to food and amusement, gives it sufficient time to dry and harden. About half an inch seems a sufficient layer for a day. By this method, in about ten or twelve days is formed a hemispheric nest, with a small aperture towards the top, strong, compact, and warm, and perfectly fitted for all the purposes for which it was intended."

In some cases birds excavate their nests in decaying timber. The tomtit and woodpecker provide examples. According to Mr. Wilson, the American woodpecker makes an excavation five feet deep and of a tortuous form to keep out the wind and the rain. The nests of the weaver and tailor birds are works of art. The weaver bird intertwines and interlaces slender leaves, and so produces a strong web for the reception of the eggs ; the tailor bird actually sewing the leaves together which form its nest. The leaves are stitched together with cotton thread when this can be found, and with vegetable fibre when thread is not available. Mr. Forbes relates that the tailor bird of the East Indies, in forming its nest, chooses a plant with large leaves, that it gathers cotton which it spins into a thread by means of its bill and claws, and that, using its beak as an awl, it deliberately sews the leaves together. Sir E. Tennent states that the baya bird of India "hangs its pendulous dwelling from a projecting bough, twisting it with a grass into a form somewhat resembling a bottle with a prolonged neck, the entrance being inverted, so as to baffle the approaches of its enemies, the tree snakes and other reptiles." This authority explains that the baya bird makes two nests—one for the male and one for the female—and that the nest of the male is provided with one or more fireflies stuck in mud near its entrance, and which by their luminosity scare away enemies Mr. Gould in his "Birds of Australia" points out that the talegallus makes no nest, but deposits its eggs in mounds of mixed sand and herbage, and that when the mass heats, the eggs are hatched ; the young birds forcing their way out of the incubating mixture and commencing an independent life from the moment they are born.

[1] From Thompson's "Passions of Animals," p. 205.

These acts betray extraordinary prescience on the part of the parents and the offspring. One of the hatching mounds, according to Sir George Grey, had a circumference of forty-five feet and a height of five feet.

As indicating prescience on the part of birds Mr. Couch relates that in the early summer of 1835 a pair of water-hens built their nest on the margin of an ornamental pond at Bell's Hill. The nest was built when the water in the pond was low. As the level of the water was being somewhat suddenly raised, on one occasion, by another pond discharging its contents into it, the nest of the water-hens was in great danger of being submerged. The birds seemed at once to realise the nature of the danger, and, removing their eggs to the bank, they set to work and industriously piled up additional sedges and twigs so as to raise the nest well above the higher water level. This done, the eggs were restored to the nest and the hen bird returned to her task of incubating. All this happened within the short space of an hour. The water-hens must have had clear conceptions of the nature of the danger and of the means of averting it.

That birds build their nests intelligently is proved by this, that they adapt them to certain localities, and avail themselves of artificial materials when civilisation places such localities within their reach. Swallows take advantage of eaves, chimneys, and outhouses; starlings and tomtits of boxes placed in convenient situations; canaries and turtle doves of artificial nests, &c.; changed conditions alter both the form and materials of nests.

Mr. Wallace thought the young birds intelligently scrutinised the nest in which they were reared, and remembered and imitated it when they came to build nests of their own. This view is opposed to the hereditary instinct theory of nest-building, but it is well worthy of consideration, as the first nest-building birds could not possibly have built their nests instinctively. As a matter of fact, reason precedes instinct—instinct on all occasions involving means to ends, that is, a knowledge of the object to be attained and the means of attaining it. Instinct, at its inception, is not blind but purposive. M. Leroy and Mr. Wilson have come to the conclusion that the nests of young birds are not so perfect as those of older birds. This means that intelligent experience counts for much in nest-building.

Before concluding my remarks on nidification or nest-building it may be useful to refer briefly to the curious habit indulged in by certain birds of laying their eggs in the nests of other birds to be hatched out, thus getting rid of the responsibility of incubating their own eggs and feeding their own offspring. The cuckoo is generally the bird selected in illustration. It is necessary, however, to premise that some cuckoos build their own nests and hatch out and feed their own young, and that a considerable number of birds do occasionally drop their eggs into the nests of other birds. The American cuckoo, for example, does not adopt the parasitic habit, and certain species of *Molothrus*, allied to the British starling, and which are not cuckoos, do lay their eggs in the nests of other birds.

Professor Alfred Newton (article "Birds," *Encyclopædia Britannica*) writes as under: "Certain it is that some birds, whether by mistake or stupidity, do not unfrequently lay their eggs in the nests of others. It is within the knowledge of many that pheasants' eggs and partridges' eggs are often laid in the same nest; and it is within the knowledge of the writer that gulls' eggs have been found in the nests of eider-ducks, and *vice versâ;* that a redstart and a pied flycatcher will lay their eggs in the same convenient hole—the forest being rather deficient in such accommodation; that an owl and a duck will resort to the same nest-hole, set up by the scheming woodman for his own advantage; and that the starling, which constantly dispossesses the green woodpecker, sometimes discovers that the rightful heir of the domicile has to be brought up by the intruding tenant."

The Australian and European cuckoos, which habitually lay their eggs in alien nests, generally select those of the hedge-sparrow, water-wagtail, titlark, yellowhammer, green linnet, and whinchat, and, by preference, the nest first mentioned (the hedge-sparrow's). This is the order stated by the famous Dr. Jenner, who devoted a large share of attention to the subject.

The parasitic habit referred to is one of the vagaries in bird life which are very difficult to explain. Taken as one of many other bird habits, it is not wholly inexplicable. The parasitic act is one of appropriation; the cuckoo and other birds, which so offend, simply take possession of the nests of other birds. This view is favoured by the fact that certain birds are continually thieving from each other. Crows during the nest-building time are constantly stealing twigs and small branches from each others' nests; magpies eagerly filch everything which glitters and can be carried off; large, strong birds rob smaller and weaker birds of their food. The thieving propensity is seen even in ants and bees; there are marauder ants and marauder bees. Moreover, egg-laying and nest-formation do not necessarily go together. The ostrich lays its eggs on the sand and leaves the sun to hatch them during the day; the male bird sitting upon and hatching them at night. The ostrich makes no nest and has few maternal cares. When nests are made, and the cuckoo and certain other birds drop their eggs into them, they do so with the knowledge that the builders of the nests will hatch out the eggs with their own. It is a case of reasoning and prevision. It is as easy to appropriate a nest as anything else. The crocodile and turtle, which deposit their eggs in sand and cover them over, act voluntarily, and are quite aware of the necessity for concealment, and

of the power of heat to hatch them out. Birds which sit upon and hatch out their eggs are also in possession of the several hatching secrets.

In the case of fish, where very little, if any, heat is required, the eggs are buried in sand, gravel, &c., by the parents to preserve them from their natural enemies. Even the fish are endowed with sufficient reason to secure the reproduction of the species. In the case of the salmon, the male fish scoops and gouges out with its strong curved under jaw a trough in the sand or gravel sufficiently large to contain the female. When the hatching cradle is completed she occupies it and deposits her spawn; the male fish, who is in constant attendance, duly shedding his milt over it. The spawning and milting process over, the male and female fish cover up the fertilised eggs with sand and gravel; the forces of nature achieve the rest. The spawning of fish is not a haphazard or chance process. The fish are fully cognisant of the business in hand. They migrate at certain periods, and often travel long distances to accomplish the spawning function, which is, in the strictest sense of the term, a rational function.

The cuckoo and other birds which lay their eggs in alien nests are no strangers to the facts of incubation. The various acts of incubation usually attributed to instinct are not explained by that term. Instinct is a blind act, but egg-laying and nest-building are not blind acts. The majority of birds make elaborate preparations for egg-laying, and their nests, which display exquisite workmanship and design, are studiously concealed or placed in inaccessible positions. Birds exercise intelligence not only in building their nests but in selecting sites for them. In the case of animals which build no nests, they display great caution as to the localities in which the eggs are to be placed; they also conceal them and so secure their safety against marauders. This is true of the crocodile and turtle. In the case of birds and other animals which build nests, they stoutly defend them and their contents against all comers. The several acts involved in egg-laying, egg-concealing, egg-hatching, nest-building, and nest-defending are not, in any sense, blind acts; they are reasonable and intelligent acts. If it be stated that the crocodile and turtle can have no knowledge of the effect of heat upon their eggs, the reply is obvious—the Creator and Maker of these animals certainly has, and He has conferred upon them the necessary endowments and knowledge for their guidance. Animals cannot be dissociated from their surroundings; neither can they be separated from the Creator or First Cause, and from the law, order, and design which pervades the universe.

Mr. Romanes, in his "Intelligence of Animals," endeavours to account for the aberrant egg-laying propensities of the European cuckoo by "natural selection," but as I show in early sections of this work there is, strictly speaking, no such thing as natural selection. There is artificial selection in the crossing of plants and the breeding of domestic animals: that is, an expert, who is possessed of and exercises intelligence and reason, can choose or select superior specimens of plants and animals of the same species, or nearly allied species, and cross them with advantage up to a point, but only up to a point, as improvement and advance are only possible within prescribed limits. Here an intelligent selector is at work. In nature there is no such thing as an intelligent selector, propagator, and breeder, if the Creator or First Cause Who designs, supervises, and upholds everything be excluded. Certainly, no plant or animal can, of itself and by itself, alter its constitution or gain advantages which it does not inherently possess. This remark is true of the lowest plant and the highest animal, man included. A man cannot voluntarily add a cubit to his stature; he cannot cause to grow, or prevent from growing, a single hair on any part of his body. He cannot develop or suppress, in his bodily organism, secretory and excretory organs. He cannot grow, or prevent from growing, muscles, blood-vessels, nerves, lymphatics, bones, and all the parts which form his physical being; he cannot produce in his own person by willing and by selection good structures and properties to the exclusion of what he regards as undesirable structures and properties. So-called natural selection takes for granted a self-directive power, which, apart from the Creator, does not exist either in plants or animals.

Mr. Darwin and his followers (Professor Haeckel included) ignore a Creator or First Cause; they also ignore design, and in so doing they rob nature of its soul, its essence, its mainspring. They endeavour to establish law, order, and sequence out of chaos. The majority of them regard matter, inorganic and organic, as self-forming and self-regulating, and they consider even life a property of matter as matter. They believe in what they regard as spontaneous generation. They attribute everything to chance. All nature inveighs against such doctrines. According to them, plants and animals are automata controlled by reflex acts, there being few, if any, strictly voluntary designed acts; but such acts can be traced in all animals, from the lowest to the highest, up to man.

If the cuckoo lays its eggs in an alien nest it does so voluntarily, deliberately, and knowingly. It elects to do so. It is not constrained to the particular act by chance, or even by so-called determining circumstances. It is not a question of instinct transmitted from a prior period, but largely one of reason and knowledge asserting themselves in the present. The bird knowingly contracts a habit, and the habit is stereotyped in the offspring by repetition. The habit was not originally a chance product; neither is the continuance of the habit an altogether blind act. It is not a question of selection by a second party, but of election by a first party.

Dr. Jenner endeavoured to account for the habit of the European cuckoos laying their eggs in alien nests by saying that the arrangement allows the cuckoos to migrate earlier than would otherwise be possible. If so, the act is a reasoned, intelligent act. Mr. Romanes argued that the egg of the cuckoo is abnormally small for the size of the bird,[1] and Dr. Baldamus added that the markings on the cuckoos' eggs correspond with those of the eggs of the bird whose nest is selected for laying the eggs in. Dr. Jenner's explanation of the parasitic habit is plausible, if not wholly satisfactory. It invokes reason rather than instinct. The size of the cuckoo's egg and its markings cannot certainly be explained by any form of so-called natural selection. A moment's reflection will show that the cuckoo cannot possibly determine either the size of its egg or the markings on its surface. Natural selection in such a case is totally irrelevant, and inadequate, either as cause or effect.

While the parasitic habit of the Australian and European cuckoo to lay eggs in alien nests is curious, the manner in which young cuckoos oust the eggs and callow young of the actual builder of the nest is not less so. The unwieldy stranger asserts himself almost as soon as he is born. Blind and featherless, he fidgets about in the bottom of the nest until he contrives to get the other contents of the nest forcibly extruded. Dr. Jenner says: "The mode of accomplishing this was very curious. The little animal, with the assistance of its rump and wings, contrived to get the bird upon its back, and making a lodgment for the burden by elevating its elbows, clambered backward with it up the side of the nest till it reached the top, when, resting for a moment, it threw off its load with a jerk, and quite disengaged it from the nest. It remained in this situation a short time, feeling about, with the extremities of its wings, as if to be convinced whether this business was properly executed, and then dropped into the nest again. With these (the extremities of its wings) I have often seen it examine, as it were, an egg and nestling before it began its operations; and the sensibility which these parts appeared to possess seemed sufficiently to compensate for the want of sight, which as yet it was destitute of."

Dr. Jenner's account is supplemented by a writer in *Nature* (vol. v., p. 383, and vol. ix., p. 123) as follows: "But what struck me most was this: the cuckoo was perfectly naked, without a vestige of a feather or even a hint of future feathers; its eyes were not yet opened, and its neck seemed too weak to support the weight of its head. The pipits (in whose nest the young cuckoo was parasitic) had well-developed quills on their wings and back, and had bright eyes partially open; yet they seemed quite helpless under the manipulations of the cuckoo, which looked a much less developed creature. The cuckoo's legs, however, seemed very muscular, and it appeared to feel about with its wings, which were absolutely featherless, as with hands—the spurious wing (unusually large in proportion) looking like a spread-out thumb. The most singular thing of all was the direct purpose with which the blind little monster made for the open side of the nest, the only part where it could throw its burden down the bank. [The latter remark has reference to the position of the nest below a heather bush, on the declivity of a low, abrupt bank, where the only chance of dislodging the young birds was to eject them over the side of the nest remote from its support upon the bank.] As the young cuckoo was blind, it must have known the part of the nest to choose by feeling from the inside that that part was unsupported."

Under date June 29, 1787, Dr. Jenner writes: "Two cuckoos and a hedge-sparrow were hatched in the same nest this morning; one hedge-sparrow's egg remained unhatched. In a few hours after, a contest began between the cuckoos for the possession of the nest, which continued undetermined till the next afternoon; when one of them, which was somewhat superior in size, turned out the other, together with the young hedge-sparrow and the unhatched egg. This contest was very remarkable. The combatants alternately appeared to have the advantage, as each carried the other several times nearly to the top of the nest, and then sunk down again oppressed with the weight of its burden; till at length, after various efforts, the strongest prevailed, and was afterwards brought up by the hedge-sparrows."

It will be noticed that even young cuckoos, blind and undeveloped, are endowed with powers which make them masters of the situation. Their actions are well directed and purposive. They are not aimless, chance actions. Every movement is a means to an end, and that end is rational and intelligent, if regard be had to the object in view. The movements cannot be referred to irritability on the part of the young cuckoos, for the same thing happened when two young cuckoos were in the same nest; neither can they be referred to extraneous stimulation on the part of the eggs and young birds which shared the nest with them. Eggs and young birds do not act as irritants to each other. The young cuckoos deliberately felt about with their featherless wings for the eggs and callow young, and also for the unprotected parts of the nest over which to tilt them; they further raised them upon their backs by the aid of their wings and rump, stood up, and clambered up the side of the nest, the more effectually to discharge them by a peculiar jerking movement from the nest. Reason and knowledge could go no further

[1] "The egg of the cuckoo is not any larger than that of the skylark, although an adult cuckoo is four times the size of that bird. And that the small size of the egg is a real case of adaptation (in order to deceive the small birds in whose nest it is laid), we may infer from the fact of the non-parasitic American cuckoo laying full-sized eggs." ("Animal Intelligence," p. 206.)

in the transaction. The ejectment of the eggs and callow young could not have been more effectually or scientifically accomplished by man himself. The movements of the young cuckoos which produced the ejectment cannot, moreover, be explained by so-called instinct or by hereditary transmission, as these movements were doubtless resorted to by the first young cuckoos introduced into alien nests. Instinct, as already explained, can only have its origin in reason and original endowment conferred by the Creator or First Cause on the individuals exhibiting it; or the Creator works in and through the individuals in each particular case. Wherever there are means to ends there is design, and design necessitates a Designer. It is not always easy to trace the sequence of events, but they invariably happen in a given order and at definite intervals of time. If the parent cuckoo be guided to lay its egg or eggs in an alien nest, so, in like manner, is the offspring guided in ejecting the rightful owners of the alien nest. The operations of the cuckoo raise the question of cruelty versus benevolence, and wrong versus right. These, however, are large subjects, which cannot profitably be discussed here. It may suffice to say, that benevolence and cruelty, and right and wrong, exist side by side in the world as we know it. Animals, and even plants, prey upon each other, and cruelty and death form part of the scheme of life as it manifests itself to us.

The keepers of zoological collections are familiar with the desolation and despair which overtake birds removed from their fellows and from old familiar haunts. They do not permit them to give way to grief and to die of inanition. On the contrary, they cram them with food and keep them going, in a sense, artificially, until their disappointment and grief have worn off. When this time arrives they feed naturally, and become reconciled to the new state of things. Birds recognise their images in looking-glasses, and also life-size pictures of themselves if well painted. In the latter case, a male bird will make love to the painted female. On one occasion, in a friend's aviary in the west of Scotland, I observed a female love-bird coquetting and greatly excited in front of a large mirror. Presently it ejected the contents of its stomach, which it plaistered against the glass, as if feeding a strange bird. No doubt the maternal instinct had asserted itself, and it insisted on feeding its own shadow. This it did on several occasions. Parrots not unfrequently call out for absent friends. Birds in many cases dream. They can be taught to perform no end of tricks, and be employed as lures for other birds when trained by fowlers. They are quick to recognise and avoid danger. When telegraph and other overhead wires were first used, birds of all kinds flew against them and were killed in large numbers. Now it is quite a rare thing to find a dead bird in the track of such wires. Birds submit with patience to operations on injured wings and legs. An eagle caught in a fox-trap in the forest of Fontainebleau had its foot greatly mangled, and bore an operation of considerable magnitude without wincing or using its powerful beak, although the head was left free. The bird called the honey-guide, according to Dr. Livingstone,[1] is eager to conduct travellers and others to bees' nests in the forest, being quite aware that if the hives are robbed they will be provided with a rich repast of pupæ or bee grubs. Dr. Livingstone puts the question: "How is it that members of this family have learned that all men, white and black, are fond of honey?" Mr. Romanes replies: "We can only answer, by intelligent observation in the first instance, passing into individual and hereditary habit, and so eventually into a fixed [so-called] instinct."

Mr. Thomas Gearing[2] gives a remarkable account of the intelligence of geese. These birds have from the earliest times been regarded as wise birds; they were, it will be remembered, the trusted keepers of the Roman Capitol. He says: "About thirty years ago the small market town in which I reside was skirted by an open common upon which a number of geese were kept by cottagers. The number of the birds was very great. . . . Our corn market at that time was held in the street in front of the principal inn, and on the market day a good deal of corn was scattered from sample bags by millers. Somehow the geese found out about the spilling of corn, and they appear to have held a consultation upon the subject. . . . From this time they never missed their opportunity, and the entry of the geese was always looked for and invariably took place. On the morning after the market, early, and always on the proper morning, fortnightly, in they came cackling and gobbling in merry mood, and they never came on the wrong day. The corn, of course, was the attraction, but in what manner did they mark the time?" Mrs. G. M. E. Campbell relates a case where a goose with a following of goslings opened a door fastened by a hook in a staple projecting from the doorpost. When the hook was raised, the door opened by its own weight. When the goose reached the door it waited for a short time, expecting it to be opened, "and then turned round as if to go away, but what she did was to make a rush at the door, and making a dart with her beak at the point of the hook nearly threw it out of the staple; she repeated this manœuvre, and succeeded at the third attempt; the door fell open, and the goose led her troop in with a sound of triumphant chuckling. How had the goose learned that the force of the rush was needful to give the hook a sufficient toss?"

Mr. W. W. Nichols and Commander R. H. Napier recount admirable examples of reasoning in pigeons. Mr. Nichols states that the central prison at Agra is a great rendezvous for the common blue pigeon. These birds resort in large numbers to the neighbouring country for food each morning, and return in the evening and slake their

[1] "Expedition to the Zambesi," 1865.

[2] *Gardeners' Chronicle*, August 3, 1878.

thirst in a tank outside the prison walls. This tank is infested with fresh-water turtles, which lie in wait for and snap the heads off the pigeons when they come to drink. The pigeons, however, warned by experience, do not alight on the edge of the tank at once, but fly across and inspect and locate the turtles in the tank before settling. Even then, they drink hurriedly, repeatedly, and warily.

Commander Napier says that on one occasion he observed a number of pouter pigeons feeding on some oats which had fallen from the nosebag of a horse which was standing at bait. "Having finished all the grain at hand a large 'pouter' rose, and flapping its wings furiously, flew directly at the horse's eyes, causing the animal to toss his head, and in doing so, of course shake out more corn. I saw this several times repeated—in fact, whenever the supply on hand had been exhausted. . . . Was not this something more than so-called instinct?"

Pigeons, if treated kindly, become exceedingly tame. My brother had a pet fantail which followed him everywhere. It sat upon his head, shoulder, and hand, and was so fond of him that whenever he appeared it made for him. I have seen him seize the bird and toss it into the air, hoping to get rid of it, but it persistently returned to him after a flight of a few yards. When residing in Venice a few years ago, a favourite pastime of mine was to watch the clouds of pigeons fluttering about and feeding in the grand square opposite St. Mark's. These birds literally walked about amid crowds of children and sightseers. That birds are not afraid of people, and are at home in large cities, is evident from this, that at Cologne (Germany) even such shy birds as hawks copulate and nest on the topmost turrets of the cathedral. I was very much struck, on my first visit to that famous city, with the bird life of the cathedral itself. On ascending one of the towers of that magnificent edifice I passed through a region of sparrows, then a region of doves, and lastly a region of hawks. The latter birds were as securely lodged as in a mountain eyrie, and the solitude was nearly as great. The hawks hunted in the country during the day, and returned to the cathedral in the evening. Seen from the street they looked, when skimming about, like swallows, for which they are no doubt often mistaken. I saw the same thing at the great cathedral of Seville (Spain). There the hawks shared the roosting stances with the storks. I also observed considerable numbers of hawks flying about certain temples on the Nile (Egypt). The Nile "temple hawks" are smaller than those found on the river itself; the river hawks being so tame and bold that they occasionally snatch chickens from the hands of the cooks, on board the river steamers, while they are being dressed.

The swallows are quite remarkable for the degree of intelligence displayed by them not only in building their nests in apparently impossible positions, but also in effectually dealing with other birds, especially sparrows, which invade and take forcible possession of their nests. When two sparrows appropriate one of their tenements they mob, fight, and try to dislodge them. On one occasion they failed to evict the intruders. The sparrows were left in possession until the young sparrows were hatched out and required food. The moment the old sparrows vacated the nest to provide the necessary pabulum, the swallows assembled in force, tore down the nest, and precipitated the young sparrows to the ground, where they perished miserably. On another occasion, a hen sparrow took possession of a swallow's nest and persistently refused to leave it. The two swallows which built the nest clung to it, but failed to regain an entrance. The situation was desperate, but the swallows were not to be outdone. They took flight, and evidently communicated their woes to a large number of other swallows, as quite a crowd collected outside the nest, each bearing in its beak a small piece of dirt. The result was disastrous for the hen sparrow. They forthwith deliberately built up the entrance to the nest, and so immured and killed the intruding tenant.

These acts on the part of swallows are clearly the outcome of a reasoning faculty. The birds designed and built a beautiful nest which was filched from them by the hen sparrow: they could not dislodge her—they therefore elected to destroy her. To do this they had to communicate with and obtain the assistance of their friends. The friends responded, and capital punishment of the sparrow was the result. Their revenge was emphatic and complete.

A case is related where two swallows built a nest in a verandah, the nest resting partly on a bell-wire. The nest was twice pulled down by the movements of the wire. The sagacious birds overcame the difficulty when they built the nest a third time; they, with great engineering skill, constructed a tunnel for the wire to run in, and within which it could move freely without detriment to the nest.

Pelicans sometimes fish lakes in concert. On such occasions they advance in line across a shallow portion of the lake, and drive the fish before them towards the shore as fishermen sometimes do.

It would be easy to multiply, almost indefinitely, examples of reasoning in birds; enough, however, have been adduced to show that they are endowed with powers of ratiocination. The reader who is specially interested in bird intelligence will have no difficulty in finding a rich harvest of knowledge illustrating the subject in the numerous admirable works on natural history, and the many interesting books of travel which exist and which are being constantly added to.

THE INTELLIGENCE OF MAMMALS

What is said of the intelligence of birds is true of the higher mammals. The mammals culminate in the primates and man, and in them the reasoning faculty attains its highest development.

It will be convenient to begin with the sea mammals—the porpoise, whale, *Halitherium*, *Rhytina*, dugong, and manatee—these leading up to the walruses, seals, and sea-lions.

§ 264. The Intelligence of the Porpoise and Whale.

The intelligence of the porpoise and whale considerably exceeds that of the fish and reptile, but is not equal to that of some birds. Porpoises and certain whales are gregarious. They hunt and play in packs or "schulles," and are remarkable for their affection for their young. They resemble fishes in their general appearance, but differ from the finny tribe in that their caudal fin or tail is placed horizontally instead of vertically (see Plate lii., Fig. 4, p. 85). The caudal fin in porpoises and whales when swimming strikes alternately from above downwards and from below upwards; a remark which holds true also of the caudal fin of the rhytina, dugong, and manatee. In the fish the caudal fin in swimming strikes alternately from side to side or laterally—the fin being made to move from right to left and from left to right in rapid succession. The peculiar position of the caudal fin or tail in the porpoise, whale, and other air-breathing sea mammals is highly indicative of design, as it enables these animals readily to plunge into deep water and to regain the surface at stated intervals for the purpose of breathing atmospheric air. When porpoises are feeding and playing near the surface their rounded backs appear like the rims of so many moving wheels. When seen in large numbers and in long lines they are sometimes mistaken for huge water snakes, the backs of individual porpoises forming what are regarded as the sinuosities and convolutions of the snake family.

The movements of the porpoise are exceedingly elegant, and the action of the horizontal caudal fin, as indicated, enables the animal to reach the surface of the water quickly, quietly, and without effort. The horizontal caudal fin, both as regards its anatomy and physiology, is a designed organ. Without it the air-breathing function could not be satisfactorily performed. When porpoises are not disturbed or excited they course along in more or less regular columns, and when they come to the surface they blow softly and breathe calmly, much as a human being does. They throw up no water in breathing. During one of my visits to the Island of Mull (Scotland) on a quiet misty afternoon I heard a whale blowing and breathing in the offing a mile or so distant. The sound that came to me in the stillness was that of a great monster breathing heavily in its sleep. The respiratory movements occurred at regular intervals, and the sounds thereby occasioned pulsated in space in a weird way, and made one feel that the leviathans of past ages were, fortunately, not yet quite extinct; the great inhabitants of the ocean having still their representatives in the waste of waters.

I have, on several occasions, carefully watched the swimming and breathing movements of the porpoise, and have been much struck with the grace, order, and regularity with which they are performed. Porpoises can swim with incredible rapidity. It is not an uncommon thing for them to disport themselves round the bows of even the swiftest steamships sailing their best. In such cases they gambol and dart about in all directions, sometimes crossing and recrossing the bows of the ship, sometimes swimming parallel with it, and sometimes flying off at a tangent on either side to considerable distances, quickly to return again. These evolutions apparently cost them no effort. They can keep up with and outrun the ship to an unknown extent. When so engaged they are evidently at play, and have a keen sense of enjoyment. If disturbed or frightened away, they return to their sport with renewed vigour and at the earliest opportunity. On one occasion, as a voyager explained to me, their gambols evidently gave umbrage to an old bull porpoise. He hounded them away from their sport, to which they continually returned; losing his temper, he struck the water a violent blow with his finely formed, powerful tail, which could be heard at quite a great distance. This was apparently the final signal to desist, as the porpoises simultaneously and suddenly disappeared.

Mr. Saville Kent, in an article on the "Intellect of Porpoises," writes as follows:[1] "The keeper in charge of these interesting animals is now in the habit of summoning them to their meals by the call of a whistle; his approaching footsteps, even, cause great excitement in their movements. The curiosity attributed to these creatures, as illustrated by the experiences of Mr. Matthew Williams, receives ample confirmation from their habits in confinement. A new arrival is at once subjected to the most importunate attention, and, advancing from familiarity to contempt if disapproved of, soon becomes the object of attack and persecution. A few dog-fish (*Acanthias* and *Mustelus*), three or four feet long, now fell victims to their tyranny, the porpoises seizing them by their tails, and swimming off with and shaking them in a manner scarcely conducive to their comfort or dignified appearance,

[1] *Nature*, vol. viii., p. 229.

PLATE CXLVI

reminding the spectator of a large dog worrying a rat. On one occasion I witnessed the two *cetacea* acting evidently in concert against one of these unwieldy fish (skates), the latter swimming close to the top of the water and seeking momentary respite from its relentless enemies by lifting its unfortunate caudal appendage high above its surface—the peculiar tail of the skate being the object of sport to the porpoises, which seized it in their mouths as a convenient handle whereby to pull the animal about, and worry it incessantly."

The disposition to gambol and play, and the power to respond to a whistle call and to follow and obey a leader, coupled with their well-known affection for their young, afford evidences of a considerable degree of intelligence.

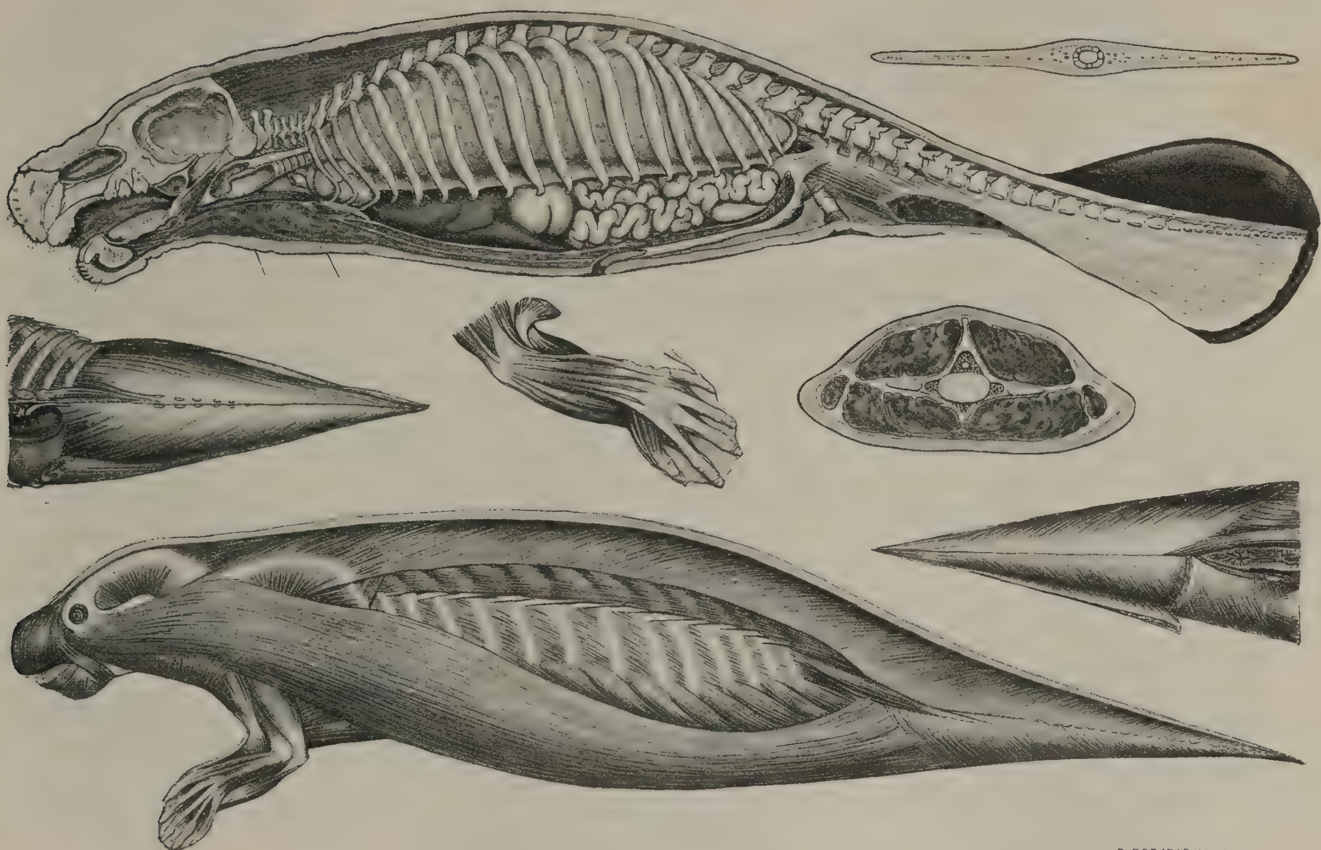
The bottle-nose and other small whales possess similar attributes. These interesting animals occasionally appear in large numbers in the north of Scotland. Their appearance is eagerly watched by the fishermen, who combine and endeavour to frighten and drive them into shoal water by surrounding them with small boats and by producing all sorts of hideous noises, accompanied by the most grotesque movements. On such occasions the excited whales, headed by an old experienced male, frequently break through the chain of boats and so escape into deep water. It is recorded that in one of these whale hunts the whole "schulle" had cleared the line of boats and effected its escape—one baby whale excepted. The distressed and excited mother of the imprisoned baby whale leapt back within the fatal circle of boats to share the captivity of its offspring. All the others followed, and all were captured and destroyed.

The female whales are splendid swimmers and divers. One has only to contemplate their general shape and fine lines and the delicate proportions of their caudal fins to be convinced of their great powers of locomotion. The caudal fins are comparatively small, but they are beautifully modelled and attached to a long lever. This thin, tapering, elastic, terminal half of the body enables them to exert their power to the best possible advantage. They strike from above downwards and from below upwards, as in the sirenidæ and the porpoises. They, however, display a greater degree of the caudal screwing, rotatory movement, a result favoured by their rounded, elongated bodies. The caudal fins act as reversing, reciprocating, elastic screw blades, and form the most effective propellers known to science.

The affection displayed by the smaller whales is shared by the larger ones—the right finner whale, for example. Mr. Scoresby relates the following in Thompson's "Passions of Animals," p. 154 :—

"In 1811, one of my harpooners struck a sucker, with the hope of leading to the capture of the mother.

PLATE CXLVII



Presently she arose close to the 'fast boat,' and seizing the young one, dragged about 600 feet of line out of the boat with remarkable force and velocity. Again she rose to the surface, darted furiously to and fro, frequently stopped short or suddenly changed her direction, and gave every possible intimation of extreme agony. For a length of time she continued thus to act, though pursued closely by the boats; and, inspired with courage and resolution by her concern for her young, seemed regardless of the danger which surrounded her. At length one of the boats approached so near that a harpoon was hove at her; it hit, but did not attach itself. A second harpoon was struck, but this also failed to penetrate; but a third was more successful, and held. Still she did not attempt to escape, but allowed other boats to approach; so that in a few minutes three more harpoons were fastened, and in the course of an hour afterwards she was killed."

This was a hard fate, and one cannot admire the cruel tactics and greed of the callous whalers, who took advantage of the known affection of the mother for its offspring, and employed the offspring as a means of destroying the parent and securing her body. The larger whales are sometimes fierce, vindictive, and dangerous. This is especially true of the spermaceti whale. These huge animals not unfrequently charge the harpooning boats and smash them to atoms with their powerful, ponderous tails. On such occasions the whale fully realises the danger of the situation, and does its best to destroy its would-be captors.

§ 265. The Intelligence of the Sirenidæ.

The members of this order are also a gradually decreasing number. The *Halitherium* and *Rhytina* are already extinct, and the dugong is rapidly becoming so.

The manatee is still found in considerable numbers in the estuaries of the South American rivers (Plate lii., Fig. 3, p. 85). It is commonly known as the sea-cow. I have had several opportunities of examining and studying this quaint animal in captivity. It lives chiefly on sea-weeds, and its movements, usually slow, are at times very rapid and vigorous. It is provided with a large, finely formed, triangular, horizontal caudal fin or tail, and this is actuated by numerous voluntary striated muscles with long caudal tendons, which enable the animal to move the tail alternately in an upward and downward direction, and to confer upon it a certain degree of torsion which converts it into a very effective propelling organ (Plate li., Fig. 1, p. 83).

Fig. 245.

Fig. 247.

Fig. 246.

Fig. 248.

The tail of the manatee is comparatively very large. It is larger in proportion than that of the porpoise, which is, nevertheless, the better propelling organ of the two. The anatomy of the manatee is given at Plate cxlvii., p. 959; for description, see pp. 1177, 1179.

Curiously enough, the larger propelling organs are not necessarily the best. It is a question of large surface and slow movements versus small surface and quick movements: the latter gain the day. In ancient times the swimming organs were relatively larger than at present.

The manatee, when resting, suspends itself by its head and shoulders in a slanting position in the water; the head being altogether out of, or near the surface of, the water. It is not characterised by any great degree of intelligence. Like the herbivora generally, it is content to browse, sleep, and lead a quiet, comparatively inactive life. In this respect it differs greatly from the walrus, seal, and sea-lion. All these are active, vigorous animals which live by the chase. The carnivora, of necessity, display a higher degree of intelligence than the herbivora upon which they prey. As already explained, hunting, predaceous animals possess larger and better brains than the animals on which they feed. But for this, the hunting animals could not waylay or overtake and destroy the animals hunted.

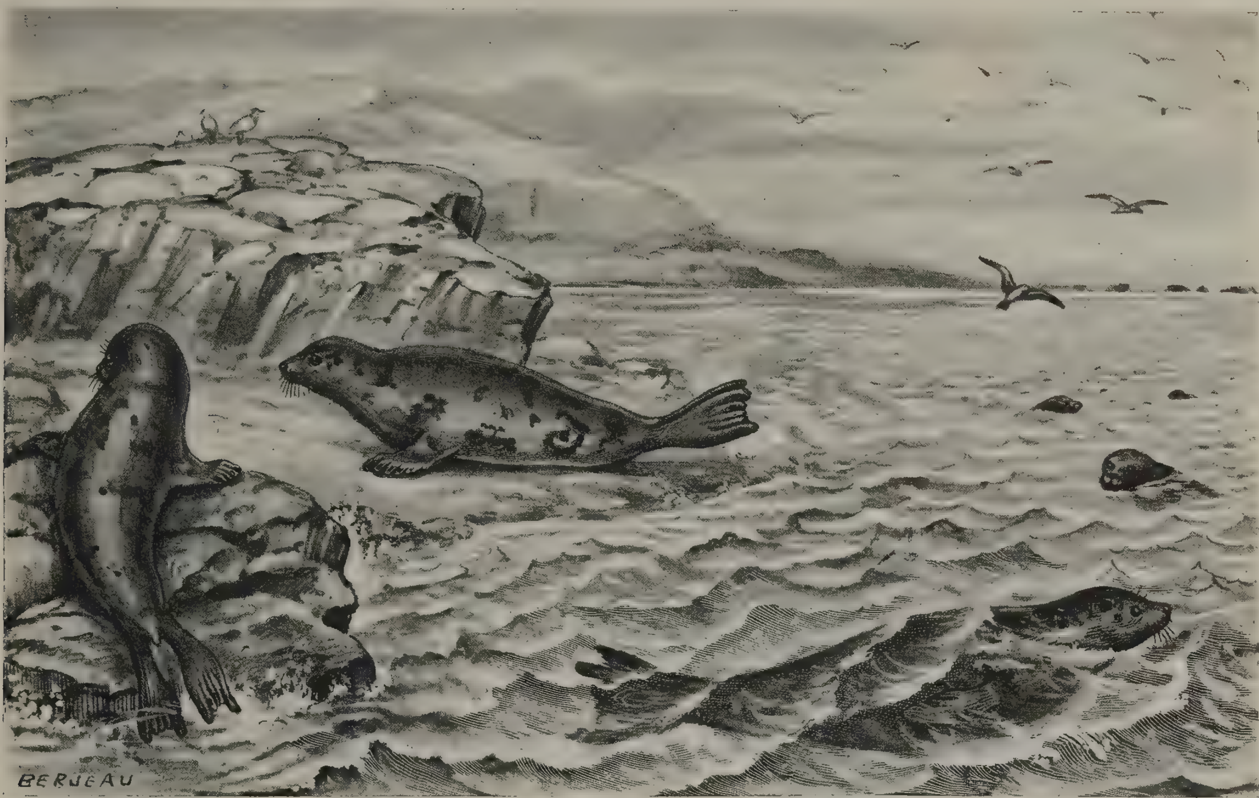
I am, thanks to the generosity of my friend Dr. James Murie, F.L.S., able to give beautiful illustrations of the Sirenidæ, he having made a special study of them. He has presented me with the foregoing important original plate (Plate cxlvi., p. 958), which shows at a glance not only the shape but also the comparative size of the several species. The flippers and swimming tail and details generally are accurately given in each case. The species figured are (above, from left to right) the manatee, halitherium, dugong, and (beneath) rhytina.

The walrus, seal, and sea-lion live almost exclusively upon fish.

§ 266. The Intelligence of the Walrus.

The walrus has a ponderous body, huge incisor tusks, specially modified limbs, and expanded, webbed, swimming extremities (Fig. 245). These several parts are means to ends, and show forth design. The large, heavy, fat body is readily supported in the water, and is proof against cold: the formidable tusks are weapons of offence and defence,

PLATE CXLVIII



and enable the animal to hold on to the ice, if need be, when resting; the anterior webbed extremities (flippers) assist the animal in sustaining itself in the water and in turning; the posterior webbed extremities being the chief organs of locomotion. The latter, when the animal swims, are vigorously lashed from side to side after the manner of a fish's tail, and propel the animal at quite a high rate of speed. I have had opportunities of studying a young walrus, and have been struck with his quiet, watchful, sagacious, semi-savage expression. He greatly resembles in his general appearance a watch-dog on the chain.

The anterior and posterior extremities or flippers are delineated with great care at Figs. 246, 247, and 248.

Many anecdotes are given of reasoning powers in the walruses in their natural habitats in the Arctic seas. Their intelligence seems to rank with that of the canine family.

§ 267. The Intelligence of the Seal.

The seals have a fishlike shape, and are provided with modified webbed swimming extremities like those of the walrus (Plate lii., Fig. 2, p. 85). They are, however, better and quicker swimmers. The fore-limbs or flippers of the seal assist in keeping it afloat and in turning; the posterior limbs acting, like fish tails, as propelling organs. The seals frequently swim on their backs, an attitude which enables them to see the fish upon which they feed, and everything beneath them. While few animals are more graceful than seals in the water, they are the most ungainly animals possible on the rocks and on the land. In the water they swim and dive with great alacrity, grace, and precision. On the land they hobble about with a semi-serpentine motion in most grotesque fashion.

The swimming of the seal is depicted at Plate cxlviii.

The anatomy of the seal is given at Fig. 249, p. 962; the skeleton of the seal at Plate xlvii., Fig. 6, p. 75.

I have frequently studied the movements of the seals and the sea-lions in captivity at the Zoological Gardens, London. I have also studied the former (the seals) in the open sea at Loch Etive, and Loch Sunart (Argyllshire), and in the estuary of the Tay (Forfarshire), Scotland.

Seals are exceedingly curious. If they are not shot at, they display considerable confidence in man, and approach sail and row-boats so closely that their various movements can be readily made out. In the sea lochs (Etive and Sunart) I have again and again watched their tactics. At first they display extreme caution, and survey the boat

and its occupants from all the points of the compass, appearing at long range in front, behind, and at either side of the object of their curiosity. If they are left to themselves, and are not disturbed, they gradually come nearer and nearer, until one is suddenly startled with the appearance of a dark round head and a pair of clear black eyes almost within oar's length. The eyes have an expression of timid wonderment, and the animal gives one the idea of a scout or strategist doing his best to obtain the greatest possible information in the least possible time. Any movement—even the slightest—in the boat is followed by his instant disappearance under water. From this he emerges in a short time, but at a greater distance, to renew his inquiries. He repeats his tactics till his curiosity is gratified and he has become more or less master of the situation.

The seal is gregarious and polygamous. At the rutting season the males engage in fierce and never-ending combat for the possession of the females. These they entice into their harems by blandishments and courtesies of the most insinuating kind, till they reach the goodly number of from ten to twenty. They are patriarchal in the conduct of their establishments, rather domineering to the females, but kind to the young so long as they do not stray from the parental home. If they do stray they are at once left to their own resources. The young take to the water naturally, but they have to acquire the art of swimming and diving. They practise their evolutions in the water at frequent short intervals, until they obtain the mastery of the fluid medium. They are self-taught, and display

Fig. 249.

caution, courage, and resource at an early age. The seal mothers are very much dominated during the breeding season by the males, to whom they tender a ready allegiance. Their affections are forced rather than volunteered, and are lightly transferred from the weaker to the stronger lords in the readjustments of the harems after combat.

The seal can be readily tamed, and when in this condition forms a most desirable pet. He can be taught to do a great many things which require the possession of memory, judgment, and a reasoning faculty. On the Forfarshire coast, in the estuary of the Tay, there was a noted old bull seal which regularly raided the salmon nets and deprived them of their choicest fish. This raiding required much intelligence, much cunning, and much boldness and resource, as it compelled the seal to enter the well or inner chamber of the net by the narrow slit or chink through which the salmon themselves entered, but through which, having forgotten the position of the chink, they could not return or escape. What the fish could not do the seal, by its superior intelligence, did easily. The seal took stock of, and remembered, the chink or aperture of entrance, which was also the aperture of exit, and having selected and secured his salmon he found his way out of the net with his coveted prize. He was a great trouble to the fishermen, as he occasionally broke portions of their nets, and they resolved to trap him. They carried out their plans very ingeniously as follows: they impaled a good-sized salmon with a long, slender pole, to the upper end of which a red flag was attached. They fixed the pole, with its salmon and flag, in a vertical position within the well or inner chamber of the net, and furnished the chink or aperture which conducted to the inner chamber with a movable curtain of net, which could be closed by the aid of cords. When all was ready the fishermen watched the red flag with a strong field glass. When it moved violently they knew the seal was inside the well of the net, whereupon they closed the movable curtain which occluded the aperture of exit. They then loosened the sustaining cords of the well in such a manner that the net, flaccid and bulky, enveloped the captured seal and made escape impossible. They secured and dragged him ashore and clubbed him on the sands, where he was temporarily interred to form a skeleton for the Natural History Museum of the University of St. Andrews.

PLATE CXLIX

In a salmon net the chink, or aperture of entrance to the well, occurs at the end of a conical-shaped avenue; the wider portion of the avenue being further away from the aperture. The salmon enter the wider portion of the avenue, and are gradually conducted to the narrowest portion thereof, where the aperture occurs. When they pass through the aperture and enter the well they forget the way out. Not so with the old seal. He understood the mechanism of the net, and went in and out of the well of the net at pleasure. He was quite content to let the fishermen catch the salmon, but he reserved to himself the right of abstracting and eating it. This action on the part of the seal displayed quite a remarkable degree of reasoning power. The facts speak for themselves, and require no comments.

§ 268. The Intelligence of the Sea-lion.

The sea-lion is even more remarkable than the seal as regards its movements and degree of intelligence (see Plate cxlix.).

I have made a special study of the anatomy and physiology of this most wonderful animal.

The sea-lion, like the walrus and seal, is provided with modified webbed swimming extremities. It differs from both in that its anterior extremities or flippers are its principal organs of locomotion. These are comparatively very large, and are true wings in that they are flexible elastic organs which taper from within outwards and from before backwards. They resemble the wings of the swift, gannet, and other birds with long, narrow, scythe-like pinions (Figs. 250 and 251, p. 964). The flippers of the sea-lion are structurally and functionally wings, and with them they swim and dive in the most graceful and effective manner possible. The sea-lions, in a sense, fly in the water, as the little auks, mergansers, and other birds do, and nothing can exceed the rapidity and beauty of their evolutions. They employ their flippers synchronously and with equal beat when they are swimming rapidly forward, and with unequal beat and alternately when they are turning to right or left. The posterior extremities are largely in abeyance during the swimming and diving movements, and are not unfrequently spread out at right angles to the body when the animal wishes to curb its speed and check or destroy its forward motion.

The flippers of the sea-lion, as indicated, are constructed on the wing type, and, as I have pointed out elsewhere, they resemble in their general configuration and action the pectoral and caudal fins of fishes. They are,

fundamentally, propelling organs, and produce forward motion by a more or less vertical, to and fro, semi-rotatory, twisting action.

It would be difficult to find a better example of design than is furnished by the flippers of the sea-lion. These occupy in some sense a higher platform than the wings of insects, birds, and bats, of which they are to be regarded as the true homologues.

The intelligence of the sea-lion is deservedly rated very high. The animal can be tamed and taught to perform

Fig. 250.

Fig. 251.

all manner of tricks, such as discharging firearms, setting off fireworks, climbing ladders, balancing, accomplishing acrobatic feats, &c. It is prompt to obey orders, and is devoted to its trainer and keeper, whom it follows about like a dog. It also displays much of the affection of the dog. Its movements on the land are as ungainly and awkward as its movements in the water are graceful and adroit.

The Intelligence of the Land Mammals in a Wild and Domesticated State.

The land mammals are as varied in character and in the degree of intelligence displayed by them as they are diverse in size and shape. They also occupy different portions of the earth's crust. Two questions of no little interest emerge here. Are the land mammals original creations in time and space for the land and the

land exclusively, or are they modifications of sea mammals which have left their native element and invaded and taken possession of the land ? Further, are the land mammals, and land animals generally, the product in each case of one male and one female in one locality, or are they the product of multiple parents in several localities ?

Having regard to the organs of locomotion and other peculiarities (especially the breathing apparatus), I am strongly of opinion that the land mammals have, from the first, been distinct from the sea mammals. Animals, as already explained, have no means at their disposal whereby they can change the configuration of their bodies and adapt their travelling organs either to the land, the water, or the air. This is also true of the breathing and other important organs. As the powers of animals are limited in the directions indicated, it follows that no amount of time, however protracted, would convert a land mammal into a sea mammal, or *vice versâ*. Animals are specially created for the media they inhabit. They are, further, not necessarily descended from a single pair of parents. The prevailing conditions of the air, water, and land in certain localities at certain periods favour the belief in multiple creations. Wherever the same conditions exist, the same or similar animals appear, not as a matter of accident, but of design and forethought. In no other way can the presence of extinct fossil plants and animals in separate and widely remote areas of the earth's crust be satisfactorily accounted for.

Even man, the highest representative of the land mammals, is believed by not a few leading scientists to have had a simultaneous origin in several centres. It is a mistake to suppose that locality and environment make plants and animals what they are. As a matter of fact, the very opposite is true ; plants and animals are specially formed and adapted for certain localities and environments. The inorganic kingdom precedes the organic kingdom but does not make it. There is no such thing as spontaneous generation, or life *de novo* and by chance. The inanimate and animate are special creations. The germ, seed, or egg of every living thing is in itself. This seems proved by the history of plants and animals in ancient geologic and modern times. Further, the simultaneous appearance and disappearance of plants and animals in the prehistoric and historic periods demand an adequate creating or building up power and an adequate disintegrating or destroying power. Mere chance cannot be credited either with the production or the destruction of plants and animals in time and space. This argument of design and adaptation to certain localities and environments, especially in animals, is not impaired by the fact that a large number of insects, and several other creatures, begin their lives in the water as water-breathers and terminate them on the land as air-breathers. In all these cases the organs of locomotion and the breathing apparatus adapted to different media at different periods are special creations, in the sense that the land and water animals themselves are special creations. The amphibia are as much special creations as the air-breathing and water-breathing animals are. The amphibia afford striking examples of adaptation and design. They do not lend themselves to a blind and irrational evolution. While certain animals can live partly on the land and partly in the water, and boast an amphibious existence, no animal can at one and the same time be an air-breather and a water-breather. In the developmental or transitional stages through which certain animals pass before they reach maturity, the breathing apparatus, and, within limits, the organs of locomotion, are modified and adapted to the exigencies of the situation, as is exemplified in the case of the young frog. The means are forthcoming, and in advance of the ends to be attained. The Creator and Designer are never dissociated.

One of the most interesting and paradoxical animals in the world is the platypus (*Ornithorhynchus anatinus*) of Australia. This most extraordinary creature has four legs, a furry skin, and resembles an ordinary quadruped. It has, however, a duck's bill and webbed swimming feet, and it lays eggs. It combines the characteristics of the quadruped and bird in a remarkable way. It cannot, however, be said to form a connecting link or transition stage of the one into the other. It is not an evolution. It is an independent animal, just as other animals are.

The platypus spends most of its time in the water, but it is an air-breather. That it is a separate creation seems proved (*a*) by its dissimilarity to all other animals, and (*b*) by its being found in only one locality. Similar remarks are to be made of the kangaroos and opossums, which are survivors of old-world forms. The pouched animals, like the platypus, belong, strictly speaking, to one centre or locality, namely Australia.

It is not proposed in this section of the work to deal with the intelligence of all the land mammals. It will suffice if a selection be made representing a more or less ascending scale of intelligence.

Amongst the lowest in the scale may be mentioned the pouched mammals. These, as indicated, are at present confined to Australia, and are represented by the kangaroos and opossums. They bring forth their young in a very immature condition, and lodge, nurse, and protect them in their large ventral dilatations or pouches. They differ from all other modern animals in possessing feebly developed anterior extremities and very large, powerful posterior extremities, to which is to be added a huge, springy, elastic tail. The posterior extremities and tail enable the animal to rest securely as on a tripod, and to take enormous leaps in the air, which result in a very rapid unique

form of locomotion.[1] The adult male kangaroo has been known to cover twenty-five feet of ground at a single bound, and its speed is such that it can successfully contend with the swiftest hounds and horses. When the female kangaroo is hunted and has young ones in its pouch it throws out one or more in the hope of saving them if it cannot save itself.[2]

One of the small Australian marsupials (*Conilurus constructor*) displays considerable intelligence in that it builds a very large, complicated, and strong nest to preserve itself and its young from the dingo dogs which abound on the Australian continent. The nest, which according to Major Mitchell[3] is "big enough to make two or three good cart loads," consists of dry sticks and brushwood deftly interlaced and matted together to form what is practically a solid, impenetrable mass. An animal which can devise and construct what is virtually a fortress against its enemies cannot be regarded as devoid of reasoning power. The nest-building propensity, it will be observed, is not confined to ants, bees, fishes, and birds.

The tripod arrangement of the powerful posterior extremities and largely developed tails of the kangaroos and opossums is found in their congeners, viz., the extinct sloth (*Megatherium*), a fine specimen of which can be seen at the famous Hunterian Museum of the Royal College of Surgeons of England; in the *Diplodocus carnegii* of the natural history department of the world-renowned British Museum, London; and in the iguanodon, several fine specimens of which are preserved in the Natural History Museum, Brussels: the major portion of which I have carefully examined.

What may be conveniently designated the tripod animals were evidently herbivora with comparatively small brains—a remark especially true of the *Diplodocus carnegii*, which has a very small head and very imperfect teeth. The tripod arrangement formed by the greatly developed powerful posterior extremities and huge tail had evidently its origin primarily in supporting the animals in a semi-erect position to enable them to browse on the tops of high reeds, on overhead branches, leaves, fruits, &c., on luxuriant overgrown copse, and on various forms of small forest trees. That the tripod animals were supplied with an abundance of rich pabulum goes without saying, when the enormous size of some of them is taken into account. The *Diplodocus carnegii* is said to have measured some eighty feet in length, and to have stood fourteen feet high. It is computed to have weighed over ninety tons.

If such an animal had been endowed with a correspondingly large brain of good quality it would have been a terror to all terrestrial beings in its vicinity, the lord of creation included.

In estimating the intelligence of animals it is not easy or safe to classify them unless in a very general way. This follows because, ever and anon, superior intelligence crops up in individuals of practically lower types.

I propose, therefore, to arrange what I have still to say under "animal intelligence" as follows:—

(*a*) Wild land animals—herbivora.
(*b*) Wild land animals—carnivora and omnivora.
(*c*) Domestic animals.

Under wild land animals (herbivora) fall the rabbit, hare, wild pig, buffalo, bison, and beaver.

Under wild land animals (carnivora and omnivora) fall the lion, tiger, bear, otter, wolf, jackal, fox, weasel, ferret, polecat, wolverine, and rat.

Under domestic animals fall the ox, sheep, goat, horse, ass, elephant, cat, dog, monkey, and man.

§ 269. The Intelligence of the Rabbit.

No animal is more familiar on the British landscape than the bunny. It gives admirable sport, and is an important item of food. In its wild state it displays considerable acumen and sagacity. It burrows deeply in the ground to protect itself and its young from its enemies. These, unfortunately, are numerous; foxes, dogs, cats, weasels, ferrets, and man all preying upon it. Its intelligence is largely displayed in the construction of its burrows and in the mode of evading its natural enemies. If a rabbit be encountered in the open it endeavours to escape in one of two ways: it either (*a*) instantly squats in the hope of escaping detection, or (*b*) it makes a sudden bolt for its hole. In its burrow it is secure, unless from the attacks of weasels, stoats, and ferrets, which are small enough to enter and penetrate its domicile in all its ramifications. The weasel is, on the whole, its most inveterate enemy. This bold, voracious little animal not only hunts the rabbit in the burrow but also in the open. I remember on one occasion at Glensanda (West Highlands of Scotland) seeing a weasel pursuing a rabbit to the death. The rabbit was quite exhausted, and the weasel kept always within three feet or so of it until it succumbed. The weasel apparently exercises some fascinating power over the rabbit, as it is otherwise impossible to understand how such

[1] In the hare, greyhound, horse, and quadrupeds generally, the posterior extremities are larger and stronger than the anterior ones, but the difference is excessive in the pouched and in certain extinct animals.

[2] Certain birds save their young, or a percentage thereof, by seizing them with their beaks or by placing them on their backs and flying off with them.

[3] *Transactions of the Linnæan Society.*

a large, swift animal does not make its escape by simply running away from its relentless pursuer. Rabbits are very prolific, and are fond of their young. As a consequence they increase so rapidly as, in many cases, to become a pest. In such cases they have to be killed off by shooting and other devices. The rabbit burrow is of two kinds, namely, single and many-chambered. The single burrow ends in a cul-de-sac, and has but one opening. It is the simplest but least safe form of burrow, if a weasel, stoat, or ferret enters it. The many-chambered or compound burrows consist of numerous compartments, with separate avenues and entrances; these in old burrows being more or less mixed up. Both kinds of burrows display considerable ingenuity and constructive skill. In the compound burrow the means of escape are greatly facilitated, but it is no uncommon thing in shooting over ferrets in a rabbit warren to find that a rabbit prefers to fall a prey to the ferret in its hole, rather than face the guns outside. This appears to be a matter of memory, experience, and judgment; the rabbit fearing the ferrets less than the firearms. When rabbits are frequently bolted by ferrets and shot at they become excessively shy. In burrows where rabbits are ferreted for the first time, they hurriedly leave the burrows, and so expose themselves unreservedly to occasionally cross fire. When a rabbit has been shot at and returns to its burrow it is next to impossible to get it to bolt a second time. This is my own experience, oft repeated.

Rabbits, like the majority of wild animals, are curious and inquisitive. This is well exemplified when a rabbit, disturbed and alarmed, makes for and reaches its hole, but pauses and turns round to contemplate the cause of its trepidation before entering. This strange habit frequently costs bunny its life. The jerky, irregular movements of the rabbit when hunted are no doubt an original device to enable it to escape. If a rabbit be shot at near its hole and fatally wounded it drags itself into the hole, from which it subsequently either emerges itself or is pushed or dragged out by its fellows. As a consequence the dead rabbit is found, as a rule, not inside but outside the burrow. This fact is explicable in two ways: (*a*) the dying rabbit leaves the burrow for fresh air, if it has the power so to do, and (*b*) if it dies in the hole, its fellows drag or push it out to admit air to the burrow and prevent subsequent putrefaction within it.

Rabbits can excavate burrows with great cleverness and despatch. They can also successfully turn out obstacles when purposely placed in their way. Thus, when they are wired or fenced off from pastures which they covet, they burrow beneath the obstruction, and emerge triumphant on the side where the forbidden pasture is located.

Rabbits are naturally very timid creatures, but the males not unfrequently engage in fierce fights, and a most extraordinary feature of their warfare is that each strives to castrate his opponent.

§ 270. The Intelligence of the Hare.

The intelligence of the hare exceeds that of the rabbit, and is displayed by its ability to select suitable places of concealment—that is, where the colour of the surroundings matches the colour of its own skin; in doubling upon its own track to elude dogs and other pursuers; in its attempts to eradicate the scent which its feet leave on the ground; in its entering into drains and other inaccessible places when hotly pursued; in its occasionally taking refuge with a flock of sheep; in its swimming long distances to attain certain ends; in its remarkable ability to undergo courses of training, and in its capacity to become domesticated.

The hare, until the Ground Game Act sounded its knell, was a picturesque and welcome object throughout the length and breadth of the land. It is now, unless in game preserves, seldom seen. No more graceful, gentle, or interesting creature could possibly be imagined. Its rich brown colour, long ears, expressive eyes, fine, strong, active limbs, and great speed made it a general favourite, and, while as a boy I hunted it both with gun and greyhound, I had nevertheless a great affection for it. To follow it on foot in the winter with my gun but with no dog to assist was no easy task. It chooses its lair or form with such discrimination and forethought that it requires a pair of very sharp, trained eyes to detect its whereabouts. In the red withered rushes, in high, tangled, coarse grass, in the furrow of the brown ploughed field, at the root of a rusty young beech, or beneath the lowest branch of a spreading conifer, its springy form, compactly folded together like a hedgehog, can be detected with difficulty. A sudden bound, and a crack from one or both barrels, and the enjoyment was over, and terminated not unfrequently in favour of puss. I never hunted the hare in snow. This is cruel, merciless work. I have frequently coursed or hunted it with greyhounds. Now that I am older I regard this form of sport as unfair if two greyhounds are employed. My favourite amusement was to course with one greyhound. This gave the hare a chance both as regards its speed and resource. It was delightful to see the agility with which the hare darted aside to let its heavy pursuer forge ahead, while it adopted a new course, and got well away before the greyhound could check its headlong career and change its direction. As the greyhound runs by sight and not by scent, it was a frequent occurrence for the hare to double back and so elude or blink its pursuer. Under such circumstances the greyhound was the very picture of incapacity and foolishness. The hare once lost, the chase was off. I used to hunt two

very well bred greyhounds (a black and a brown) as a rule singly, but occasionally as a pair. On one occasion I saw the black dog, which was exceedingly fleet, run a hare by himself into a drain. On another occasion I saw him force another into a pile of stacked wood. Fortunately for the hares, he could not follow on either occasion.

The black dog had the swifter heels, but the brown dog the better head. The black dog was frequently "blinked" and befooled; the brown dog almost never.

Hares are exceedingly tame and sportive at the mating season. At this period they coquet about, fight and play by turns, and their frolics are occasionally most amusing. They are naturally of a very gentle disposition, and are readily tamed.

Cowper the poet, who was fond of tame hares, thus speaks of one of them:[1] "Puss was ill three days, during which time I nursed him, kept him apart from his fellows, and by constant care, &c., restored him to perfect health. No creature could be more grateful than my patient after his recovery, a sentiment which he most significantly expressed by licking my hand, first the back of it, then the palm, then every finger separately, then between all the fingers, as if anxious to leave no part of it unsaluted; *a ceremony which he never performed but once again upon a similar occasion.* Finding him extremely tractable, I made it my custom to carry him always after breakfast into the garden. . . . I had not long habituated him to this taste of liberty before he began to be impatient for the return of the time when he might enjoy it. He would invite me to the garden by drumming upon my knee, and by a look of such expression as it was not possible to misinterpret. If this rhetoric did not immediately succeed, *he would take the skirt of my coat between his teeth and pull it with all his force.* He seemed to be happier in human society than when shut up with his natural companions."

This tame hare certainly exercised a faculty which could only be designated rational.

It is in the wild state that the hare displays its discrimination, forethought, and cunning to most advantage. Mr. Yarrell relates a case of a hare (evidently a buck) which inhabited a small island in a large harbour in the North of England. This hare, when in rut, swam the better part of a mile to the shore, where it consorted with a doe which came down from the hills. On one occasion the pair were seen flirting on the shore; the buck leaving her from time to time to ascertain the state of the tide. It left her and swam back to its island in a straight line at exactly high water, when the tide was neither flowing nor ebbing. It realised that a current either way would have carried it beyond the island and resulted in its destruction.

The following descriptions bearing on the intelligence of the hare are given by Mr. Loudoun in his "Magazine of Natural History" (vol. iv., p. 143), and by M. Jaques du Fouillouse in his "Manuel du Chasseur": "The hare is especially conscious of the scent left by its feet, and of the danger which threatens it in consequence; a reflection which implies as much knowledge of the habits of its enemies as of its own. When about to enter its seat for the purpose of rest, it leaps in various directions, and crosses and recrosses its path with repeated springs; and at last, by a leap of greater energy than it has yet used, it effects a lodgment in the selected spot, which is chosen rather to disarm suspicion than to protect it from injury. . . . It has, too, been known, when pursued to fatigue by dogs, to thrust another hare from its seat and squat itself down in its place. . . . It has been known, after a long chase, to creep under the door of a sheep-house and rest among the cattle, and when the hounds were in pursuit, it would get into the middle of a flock of sheep and accompany them in all their motions round the field, refusing by any means to quit the shelter they afforded. The stratagem of its passing forward on one side of a hedge, and returning by the other, with only the breadth of the hedge between itself and its enemies, is of frequent occurrence, and it has even been known to select its seat close to the walls of a dog-kennel. This latter circumstance, however, is illustrative of the principles of reflection and reasoning; for the fox, weasel, and polecat are to the hare more dangerous enemies than the hound; and the situations chosen were such as those ferocious creatures were not likely to approach. A gentleman was engaged in the amusement of coursing, when a hare, closely pressed, passed under a gate, while the dogs followed by leaping over it. The delay caused to her pursuers by this manœuvre seems to have taught a sudden and useful lesson to the persecuted creature; for as soon as the dogs had cleared the gate and overtaken her, she doubled and returned under the gate as before, the dogs again following and passing over it. And this flirtation continued backwards and forwards until the dogs were fairly tired of the amusement; when the hare, taking advantage of their fatigue, quietly stole away."

Mr. Couch[2] relates the following: "When followed by dogs it will not run through a gate, though this is obviously the most ready passage; nor in crossing a hedge will it prefer a smooth and even part, but the roughest, where thorns and briars abound; and when it mounts an eminence it proceeds obliquely, and not straightforward. And whether we suppose these actions to proceed from a desire to avoid those places where traps may probably have been laid, or from knowing that his pursuers will exactly follow his footsteps, and he has resolved to lead

[1] "The Life and Works of William Cowper," p. 633 (Tegg's edition).
[2] "Illustrations of Instinct," p. 177.

them through as many obstacles as possible, in either case an estimation of causes and consequences is to be discovered."

Other examples of reasoning in the hare might be cited in plenty.

§ 271. The Intelligence of the Wild Pig.

The habits and peculiarities of the pig in a state of nature are tolerably well known. It has many enemies, the sweetness and delicacy of its flesh proving an attractive bait to most of the larger carnivora. It is more or less gregarious and social, and bands together for purposes of defence. A pair of pigs and their numerous young form a little colony, which is, in a sense, independent. They are very active, and, on the whole, cleanly animals; their occasional wallowing in the mire during great heat being simply a means of cooling themselves. They pick up acorns and fallen fruit, and grub about for roots, which yield them a substantial pabulum. They are invariably in good physical condition; a fact due to their industry and power of catering, even in adverse circumstances. The fact that they are frequently hunted by the larger carnivora and man, in their native forests, has made them exceedingly clever in eluding pursuit and in devising means of escape. Left to themselves they are harmless, and in no way aggressive. If hunted by man or beast the boars fight fiercely, and in not a few instances turn upon and rend their pursuers. Pig-sticking, even on horseback, is by no means a safe amusement. Wild boars are provided with immense tusks, which inflict terrible injuries, and their hides are so strong and tough as to be almost impervious. The catalogue of disasters at boar hunts is frequently a lengthy one. Wild boars possess enormous strength, and are furnished with powerful weapons of offence; their grizzly, tough skin acting as a very effective shield. Old sows are, in some senses, as dangerous as the boars, especially when they have a litter of pigs under their charge. Wild pigs have the power and the will to defend themselves.

Mr. Thompson, in his "Passions of Animals" (p. 308), thus speaks of them: "Wild swine associate in herds, and defend themselves in common. Green relates that in the wilds of Vermont a person fell in with a large herd in a state of extraordinary restlessness; they had formed a circle with their heads outwards, and the young ones placed in the middle. A wolf was using every artifice to snap one, and on his return he found the herd scattered, but the wolf was dead and completely ripped up. Schmarda recounts an almost similar encounter between a herd of tame swine and a wolf, which he witnessed, on the military positions of Croatia. He says that the swine, seeing two wolves, formed themselves into a wedge, and approached the wolves slowly, grunting and erecting their bristles. One wolf fled, but the other leaped on to the trunk of a tree. As soon as the swine reached it they surrounded it with one accord, when, suddenly and instantaneously, as the wolf attempted to leap over them, they got him down and destroyed him in a moment."

The pig in its domestic state has long been noted for its intelligence, and it has been taught no end of surprising tricks. The "learned pig" is a familiar exhibit at country and other fairs. In the farmyard it has been known to undo the fastenings of gates, and open latches which it was believed required the presence of human hands.

One of the most remarkable cases of intelligence in a domestic pig is recorded by Mr. Bingley in his "Memoirs of British Quadrupeds" (p. 452). The following is the account drawn up at his instigation by Sir Henry Mildmay: "The Toomer brothers were King's keepers in the New Forest, and they conceived the idea of training a sow to point game. This they succeeded in doing within a fortnight, and in a few more weeks it also learnt to retrieve. Her scent was exceedingly good, and she stood well at partridges, black game, pheasants, snipes, and rabbits, but never pointed hares. She was more useful than a dog. According to Mr. Youatt,[1] Colonel Thornton also had a sow similarly trained. The same author says that a sow belonging to Mr. Craven had a litter of pigs, one of which, when old enough, was taken and roasted, then a second and a third. These were necessarily taken when the mother returned in the evening from the woods for supper. But the next time she came she was alone, and, as her owners were anxious to know what had become of her brood, she was watched on the following evening, and observed driving back her pigs at the extremity of the wood, with much earnest grunting, while she went off to the house, leaving them to wait for her return. It was evident that she had noticed the diminution of her family, and had adopted this method to save those that remained."

Mr. Stephen Harding writes: "On the 15th ult. (Nov. 1879) I saw an intelligent sow pig, about twelve months old, running in an orchard, going to a young apple tree and shaking it, pricking up her ears at the same time, as if to listen to hear the apples fall. She then picked the apples up and ate them. After they were all down she shook the tree again and listened, but as there were no more to fall she went away."

[1] "On the Pig," p. 17.

The fact that the pig in a state of domestication can be so highly trained as to take such an interest in mundane affairs speaks volumes for its intelligence. The various acts which it has been known to perform cannot possibly be explained by the indefinable and meaningless word instinct.

§ 272. The Intelligence of the Buffalo.

This noble beast of the chase (the wildest and freest of its kind) occurred until lately in countless numbers on the prairies of America. It is now seldom met with on that great continent. A small herd is fortunately preserved in Yellowstone Park, that splendid American asylum for wild animals. The extinction of the buffalo in America is not due to the hunting propensities of the Red Indian, who slaughtered the animal for food and other luxuries, but to the insensate craze for so-called "sport" of white men, and to their cupidity and greed for hides, which induced them to kill off, ruthlessly, young and old, in season and out of season. This campaign of extirpation had done its fatal work before the American Government in its carelessness or stupidity thought fit to interfere. The world cannot afford to have its wild animals exterminated.

While the buffalo has to all intents and purposes been exterminated in the New World, large numbers still exist in the Old. The buffalo is naturally of a taciturn and fierce disposition; a remark especially applicable to the bulls, which, in many cases, attain enormous dimensions. They are the guardians of the herd, and, while they fight freely and fiercely among themselves, they band together, surround, and protect it in times of danger. I have myself seen the same strategy adopted by the bulls of the aboriginal white cattle of Scotland located in the great ancient forest of Cadzow (famous for its old oaks), Hamilton, Lanarkshire, the property of his Grace the Duke of Hamilton. Impelled by an enthusiastic love for wild animals I, on one occasion, incautiously strayed too near the herd. It was straggling in browsing order, but as soon as I put in an appearance in its vicinity, the cows and calves were collected in a central knot, and the bulls, separating themselves, commenced to circle round in steady fighting order, lowering their heads and bellowing as they did so. It was a magnificent sight, and I felt that, as far as I was concerned, further advance meant possible destruction. The wild white cattle of Scotland have black muzzles and hoofs, and are characterised by fine symmetry. They are the very embodiment of power and courage. They permit of no familiarity. If their calves are to be abstracted for any purpose, they have to be picked up hurriedly, and as occasion offers, by keepers on the fleetest of horses. If a few are to be slaughtered, as is done annually, for the poor of the town of Hamilton, they require to be shot in certain parts of the forest, as they cannot with safety be captured alive.

The late Dr. David Livingstone, whom I knew personally, and who was a native of Blantyre, a suburb of Hamilton, thus writes of the African buffalo: "I have known him, when pursued by hunters, to turn back to a point a few yards from his own trail, and then lie down in a hollow for the hunter to come up—a fact which displays a level of intelligence in this animal surpassing that which is met with in the carnivora."[1]

He adds: "It is curious to observe the intelligence of game; in districts where they are much annoyed by fire-arms they keep out on the most open spots of country they can find, in order to have a widely extended range of vision, and a man armed is carefully shunned. But here, where they are killed by the arrows of the Balonda, they select for safety the densest forest, where the arrow cannot be easily shot."

In this connection I may state that my friend Sir John Kirk, who was Dr. Livingstone's right-hand man on several of his expeditions, informed me that on their first journeys to the interior of Africa the wild elephants were quite tame, and allowed them to approach within shooting distance without fear or favour. After a single indiscriminate rifle fusilade they stampeded, trumpeting as they went, and never after could the hunters get within range unless after the most lengthened, elaborate, and careful stalking. Of course the elephant is to be regarded as one of the most sagacious and wisest of animals, and one sharp lesson was, under the circumstances, sufficient indelibly to impress the herd. Sir John also informed me that a wounded bull buffalo was one of the most dangerous of animals. He said his habit was suddenly to turn back on the hunter and charge the smoke of his rifle (smokeless powder was not then in existence). If by any chance the hunter did not have time to change his position he was inevitably crushed and killed.

Sir J. E. Tennent writes of the buffalo as follows:[2] "The temper of the wild buffalo is morose and uncertain; and such is its strength and courage, that in the Hindu epic of the 'Ramayana' its onslaught is compared with that of the tiger. It is never quite safe to approach them if disturbed in their pasture, or alarmed from their repose in the shallow lakes. On such occasions they hurry into line, draw up in defensive array, with a few of the oldest bulls in advance; and, wheeling in circles, their horns clashing with a loud sound as they clank them together in their rapid evolutions, they prepare for attack; but generally, after a menacing display, the herd betake themselves

[1] "Missionary Travels," p. 328.

[2] "Natural History of Ceylon," pp. 54, 56.

to flight; then, forming again at a safer distance, they halt as before, elevating their nostrils, and throwing back their heads, to take a defiant survey of the intruders."

As indicating the tractability and sagacity of the buffalo when tamed I quote the following from Sir J. E. Tennent: "A bell is attached to its neck, and a box or basket with one side open is securely strapped on its back. This at night is lighted with flambeaux of wax, and the buffalo bearing it is slowly driven into the jungle. The huntsmen with their fowling-pieces keep close under the darkened side, and as it moves slowly onwards, the wild animals, startled by the sound and bewildered by the light, steal cautiously towards it in stupefied fascination. Even the snake, I am assured, will be attracted by this extraordinary object; and the leopard, too, falls a victim to curiosity."

Mr. Jesse in his "Gleanings, &c." (vol. i., p. 328), gives the following important information regarding the intelligence of the buffalo at the Zoological Farm on Kingston Hill, which was of a surly, vicious temper, and had a ring through its nose to which was attached a short chain with another ring, four inches or so in diameter. He says: "In grazing the buffalo must have put his foot on this ring, and in raising his head the jerk naturally produced considerable pain. In order to avoid this the animal has the sense to put his horn through the lower ring, and thus avoid the inconvenience he is put to. I have seen him do this in a very deliberate manner, putting his head on one side while he got his horn through the ring, and then shaking his head till the ring rested at the bottom of the horn."

Here, then, was deliberate forethought and an obvious adaptation of "means to ends." The buffalo remembered, reasoned, and judged. The putting of the ring on the horn was not a chance action, but a spontaneous voluntary action calculated to secure immunity from pain and obtain physical freedom and comfort.

Fig. 252.

The bison so closely resembles the buffalo in its general characteristics that it need not be separately considered. The following anecdote related by Mr. Thompson in his "Passions of Animals" (p. 308) confirms what is here stated: "The sagacity with which the bisons defend themselves against the attack of wolves is admirable. When they scent the approach of a drove of these ravenous creatures, the herd throws itself into the form of a circle, having the weakest and the calves in the middle, and the strongest ranged on the outside; thus presenting an impenetrable front of horns."

§ 273. The Intelligence of the Beaver.

The beaver is on a comparatively very high level as regards intelligence (Fig. 252). Like the ant and the bee, it lives in communities, and is possessed of great constructive skill. In some respects it is even more remarkable than those insects, as it has to deal with ever-varying and novel conditions, which call forth original reasoning powers of a decidedly advanced order. Few, if any, of the constructive feats of the beaver can be referred to so-called instinct or blind adaptation of means to ends. On the contrary, a vein of pure reason can be traced in nearly everything it does. Not only so, but it is thoughtful and prescient to an extraordinary degree. It anticipates wants, and makes the necessary preparation to turn them to the best account. It leaves nothing, or next to nothing, to chance. All, or nearly all, its actions are the outcome of reflection, judgment, and conscious effort. This will be readily understood from an enumeration of its achievements:—

1. It builds its dams, lodges, burrows, and waterways in the vicinity of the timber, the bark of which supplies it with food.

2. It gnaws through with its teeth the trunks of the trees in order to get at and secure the bark of the smaller branches, which it greatly prefers to the older and thicker.

3. It gnaws through the trees in such a manner as to cause them to fall in particular directions, either towards or away from the dams, as suits its convenience.

4. When the timber is close to the beaver pond it is made, on some occasions, to fall into the pond directly, an arrangement which enables the animal to get at the branches and young, succulent bark with little labour, and no loss of time.

5. When the timber is remote from the pond the beaver makes canals between it and the dam for its easy conveyance by water. These canals reveal great skill and engineering dexterity. They are cut in the most business-like way, have vertical sides, and are often of enormous extent. Mr. Lewis H. Morgan,[1] a leading authority on beavers, describes the canals as from 3 to 5 feet wide, 3 feet deep, and, in some cases, hundreds of feet long. He gives a diagram of one where the canal is terraced on higher levels by the aid of three crescent-shaped dams, with what are virtually three locks, each with a rise of 1 foot (Fig. 253). The first canal measures 450 feet, then a rise of 1 foot occurs and a small dam: the second canal measures 25 feet, then a rise of 1 foot and a larger dam; the third canal measures 47 feet, then a rise of 1 foot and a still larger dam. (The dimensions of the dam are given in the diagram.) The three dams collect water for, and supply, the three canals; and the canals are fed by an outlet on the upper margin of the dams—this outlet being the highway of the beavers for carrying and floating their timber to the beaver pond.

The canals and dams figured and described are not accidental structures. On the contrary, they are carefully designed and skilfully executed works, and reveal quite a profound knowledge of engineering and hydraulics. The obstacles to their construction are surmounted as they present themselves—a fact which rules so-called instinct out of the question, and establishes a reasoning faculty in beavers.

Mr. Morgan gives another instance of canal cutting which emphasises the foregoing. In this case the timber to be utilised for food was 150 feet from the beaver pond, and situated on a rising slope. The canal was cut to

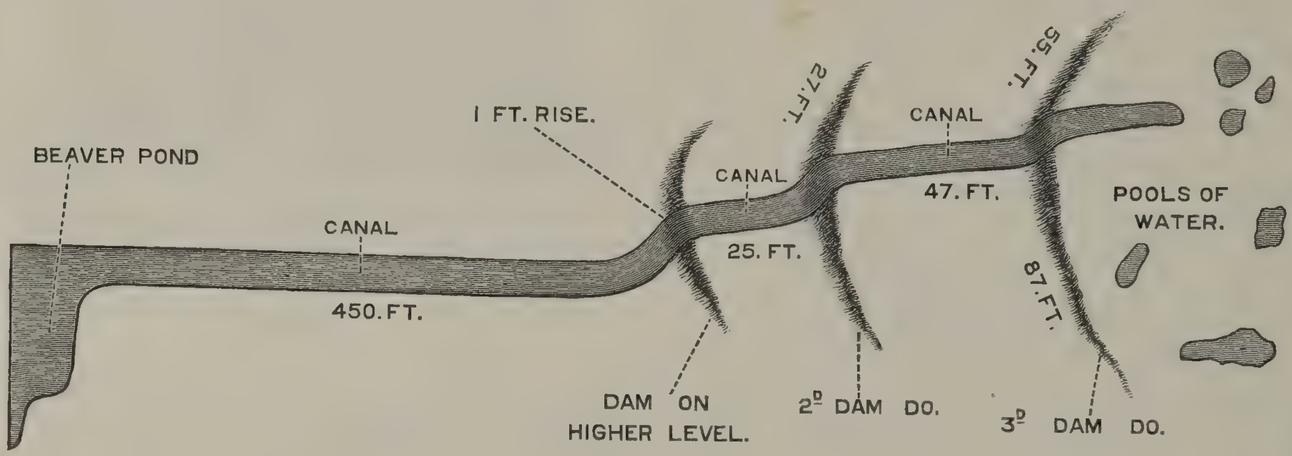


Fig. 253.

the edge of the slope, and then made to bifurcate or branch at right angles in opposite directions—one arm or branch of the bifurcation measuring 100 feet, and the other 115 feet. A water frontage of 215 feet was thus supplied; the frontage virtually supplying the beavers with a quay of that extent for shipping the timber to be floated down the canal to the beaver pond.

Mr. Morgan gives a third and not less remarkable instance of forethought and prescience on the part of the beavers. It happened that the river on which they were located made a considerable bend or loop. The beavers, to save the time and avoid the exertion required for swimming round the loop, cut a canal across its narrowest part and so established and utilised their own waterway. The engineers of the Panama Canal have done nothing more.

What has been said of beaver canals and dams applies with equal truth to beaver burrows and lodges (houses of the beavers). These also are specially constructed to meet particular requirements in each given case.

6. The beaver constructs simple and compound dams, burrows, lodges, and waterways in a great variety of situations, and modifies and adapts them perfectly to the requirements of each particular case.

7. It so places and constructs its dams and their entrances and exits, that it can regulate with the utmost nicety the amount of water which enters and leaves the dams. It thus guards against floods and too great a supply of water, and drought and too scanty a supply.

8. The construction of the dams, burrows, lodges, and waterways reveals the greatest possible discrimination and skill, both as regards the material employed and the disposition of the material.

9. The dams, in many cases, are correlated, that is, there are supplemental or accessory dams which contribute to the efficiency and strength of the principal dam. Thus it is no uncommon thing to see one small dam above, and another below, the chief one; the upper dam breaking the rush of water during floods, and the water of the lower dam acting as a buttress of support to the dyke or retaining wall of the more important central dam.

[1] "The American Beaver and his Works." Lippincott & Co., 1868.

10. Twigs, sticks, reeds, and clay are employed in the construction of the dams, and these are so combined as to yield the best results in the matter of endurance and strength. The original structures are judiciously repaired from time to time, and new material added. The "wear and tear" of the dams are duly provided for. There are two kinds of dams—the "stick dam," adapted for sluggish, shallow streams, and the "solid bank dam," adapted for rapid, deep streams. The former is composed of interlaced stick and pole work on its lower surface, with the same material plus a coating of earth on its upper surface; the latter has more brush and mud worked into its construction, particularly on its faces. In the stick dam the water percolates through; the discharge in the solid bank dam taking place through an indentation in the crest of the dam purposely made. The indentation is increased or diminished according to circumstances, and the depth of the dam thus regulated. Curious to relate, stones of from one to six pounds are occasionally employed in dam formation to add weight and density. These the beaver carries, as it does its timber, mud, &c., by holding them between its forelegs and chest, walking meanwhile on its hindlegs.

11. The dams are occasionally very large. Professor Alexander Agassiz[1] gives an account of one which was 650 feet in length, and 3½ feet in height. It had its lodges or habitations and its canals or waterways, correspondingly developed. Taking into account the slow formation of bogs, and the existence in certain of them of beaver-gnawed trees and beaver dam foundations, Agassiz came to the conclusion that the construction of the largest beaver dams may have involved centuries or even thousands of years of continuous work. He also attributes the present geographical features and climate of certain districts to beavers; they having cleared the ground of trees, and, by their dams, submerged land which was originally densely wooded.

The following is an approximate of a dam according to Mr. Morgan: Height of dam, from 2 to 6 feet; width of base of dam on section, 6 to 18 feet; length of slope on lower face of dam, 6 to 13 feet; length of slope on upper face of dam, 4 to 8 feet; difference in depth of water above and below dam, 4 to 5 feet.

12. The beaver lodges or habitations are of three kinds, namely, the island, bank, and lake lodges. The lodges have two entrances, both being rudely arched, with a roof of interlaced sticks filled in with mud intermixed with vegetable fibre.

13. The burrows of the beaver consist of straight, curved, or tortuous passages scooped out of the land and entered under water. They have no external openings except such as are required for breathing purposes. They form secure places of retreat in time of danger. The lodges are erected on, or in the vicinity of, the pools, and are the chambers in which the young are reared. They are provided with a basement or floor, from which rises a round or oval compartment composed of sticks, brushwood, and mud. The lodges vary in size; the older ones being the larger, from the fact that all repairs are made to the outside of the structures. It occasionally happens that an old lodge has a diameter of 7 or 8 feet. The lodges, as a rule, are entered from beneath by one or more underground passages. Some authorities regard the lodges as modified burrows, but this is doubtful.

14. The beaver exercises extraordinary caution and forethought in selecting the site of its lodge. It places it in or over a pool protected and deep enough not to be frozen to its bottom in winter; so situated that it will not be drowned by floods, and where it will not lack water in dry seasons; where, in fact, the climate and water level will be fairly constant or capable of being rendered so, and where its swimming, diving, wood-cutting, wood-carrying, and feeding operations will not be unduly interfered with.

15. The beaver adapts itself to various surroundings. In the Cascade Mountains it lives principally in burrows on the margins of streams, and seldom constructs either dams or lodges. On the Upper Missouri, where the banks of the river for long stretches rise vertically upwards from 2 to 8 feet, it cuts narrow inclined planes in the banks at intervals—the so-called "beaver slides." The beaver slides begin at the surface of the water, and form an angle of 45° or thereabout, and are continued until they reach the surface of the land above. They form convenient means of communication with the water and the elevated banks, and provide entrances and exits between the river and the land. The beaver has worked out the subject of landways, waterways, and subways. It has also solved the problem of locks and sluices by its dams at various levels, and by its canals in connection therewith. The beaver has proved itself a master in various departments of physics.

16. The intelligence of the beaver becomes evident when its mode of cutting up and storing away the branches and bark on which it feeds is taken into account.

The animal first fells the tree, gnawing the trunk through with its teeth. It then cuts the smaller branches, from 2 to 6 inches in diameter, into short lengths; the length being shorter as the branch is thicker and heavier. Its mode of cross-cutting the branches is scientific to a degree. It gnaws through one half, and then attacks the other and opposite half. To cut the branch through from one side would require a much wider and deeper notch, and so involve more time and labour. The cuttings are moved along by shoving and rolling with the hips sideways,

[1] "Note on Beaver Dams," p. 101 *et seq.* (*Proc. Boston Soc. Nat. Hist.*, 1869.)

the leg and tail of the beaver acting as levers until the pond is reached, whence they are floated to their destination, to be anchored in the bottom of the pond or stored in the lodge until required.

17. Last nor least, the beaver lays in an ample stock of provisions for the winter, and these it stows away in places of security, but where they can be readily reached and enjoyed in the hour of need.

While the beaver is gregarious, it is eminently domestic in its own particular family circle. A pair of beavers have their own family of two or three, and their own burrows and lodges. The young ones shift for themselves, and migrate when they are three years old. It happens occasionally that the old beavers migrate up stream and the young ones down stream; their burrows and lodges being taken possession of by other beavers which are also on the move. The burrows and lodges, in a thriving beaver settlement, are never empty.

The beaver is, on the whole, the best animal to settle the question of so-called instinct versus reason. Mr. Romanes, who is an advocate for instinct *per se*, is sorely puzzled and exercised with the doings of this remarkable animal. He cannot explain its doings by instinct, and is loth to admit that they are the outcome of pure reason. In his "Animal Intelligence" (p. 367) he says: "Indeed there is no animal—not even excepting the ants and bees—where instinct has risen to a higher level of far-reaching adaptation to certain constant conditions of environment, or where faculties, undoubtedly instinctive [?], are more puzzlingly wrought up with faculties no less undoubtedly intelligent. So much is this the case that, as we shall presently see, it is really impossible by the closest study of the pyschology of this animal to distinguish the web of instinct from the woof of intelligence; the two principles seem here to have been so intimately woven together, that in the result, as expressed by certain particular actions, it cannot be determined how much we are to attribute to mechanical impulse, and how much to reasoned purpose."

Continuing his remarks in connection with the regulation of the water supply in the beaver dams (p. 377), he adds: "It is obvious we have here presented a continual variation of conditions, imposed by continual variations in the amount of water coming down; and it is a matter of observation that these variations are met by the beavers in the only way that they can be met—namely, by regulating the amount of flow taking place through the dams. It will, therefore, be seen that we have here to consider a totally different case from that of the operation of pure instinct, however wonderful such operation may be. For the adaptations of pure instinct only have reference to conditions that are unchanging; so that if in this case we suppose pure instinct to account for all the facts, we must greatly modify our ideas of what pure instinct is taken to mean. Thus we must suppose that when the beavers find the level of their ponds rising or falling, the discomfort which they experience acts as a stimulus to cause them, without intelligent purpose, either to widen or to narrow the orifices in their dams as the case may be. And not only so, but the conditions of stimulation and response must be so nicely balanced that the animals widen or narrow these orifices with a more or less precise *quantitative* reference to the degree of discomfort, actual or prospective, which they experience. Now it seems to me that even thus far it is an extremely difficult thing to believe that the mechanism of pure or wholly unintelligent instinct could admit of sufficient refinement to meet so complex a case of compensating adaptation; and this difficulty increases still more as we contemplate additional facts relating to these structures."

The passages here quoted are disappointing, and, from my point of view, eminently unsatisfactory. They seek to draw a hard and fast line between so-called instinct and reason, and to establish instinct and reason as two separate principles in psychology. No such line can be drawn, and it is impossible, it appears to me, to determine where so-called instinct stops and reason begins, and *vice versâ*. As I have shown in a previous section of this work, reason always precedes so-called instinct either in the individual or the race, and reason and instinct are essentially and truly parts of one and the same thing. Wherever there is modification and adaptation of "means to ends" there is reason either in the animal manifesting it, or in the Designer and Maker of the animal. An intelligent result cannot be obtained by mere mechanical agencies blindly or by accident. Instinct is, at best, the mere automatic performance of rational acts due to frequent repetition long continued. These automatic acts are not confined to animals. On the contrary, they have a place in human psychology.

As a matter of fact, the so-called instinctive acts both in man and in animals are acts of reason repeated until they become automatic. In other words, they are voluntary acts repeated until they become involuntary ones. We have frequent examples of this in our own persons. We can, as adults, walk without thinking or effort, but we had, as children, to learn to walk, and the learning involved voluntary and reasoned effort oft repeated. In like manner, a trained musician can play off a solo on the pianoforte which he has voluntarily and laboriously learned, and carry on a conversation at the same time. The double performance was impossible when he was learning his piece and before he had mastered it. Similarly, the art of balancing, of suddenly distinguishing between hot and cold, &c., had all to be acquired by training and conscious effort. The power to balance and to distinguish temperature, &c., now performed automatically, had its origin in reason. The mere frequent repetition of an act does not, strictly speaking, convert what is essentially a rational, intellectual act into a blind, mechanical one. The

term instinct, if employed at all, must be taken to represent a form of reason, and be regarded as a sign of intelligence.

Seeing reason and instinct cannot be dissociated, it is evident that the latter, when used, must be defined. The lax employment of the term instinct has introduced inextricable confusion in animal psychology, and the sooner it has limits set to it, or is discarded, the better. Everything considered, I am inclined to believe it would be safer to taboo the word "instinct" altogether. A word cannot have two diametrically opposite meanings, which instinct is erroneously supposed to have. It represents, according to modern usage, blind mechanical power acting intelligently and of set purpose.

After what is here stated I need scarcely add that I regard the several extraordinary performances of the beaver as the outcome not of instinct but of reason pure and simple.

§ 274. The Intelligence of the Lion, Tiger, and Bear.

Comparatively little is known of the great carnivora in their wild state. They prowl about secretly during the night in remote, unfrequented places, where it is next to impossible to study their habits. Opinion is divided as to their courage. Until lately the lion was credited with all kinds of apocryphal daring. "Bold as a lion" has been accepted as more or less a truism. Recently suspicion has attached to the noble qualities of the "king of the forest"; not a few African travellers and hunters giving it as their opinion tbat, unless when goaded by hunger, he is rather a cowardly animal. A friend of my own, who has just returned from big game shooting in Africa, expressed this opinion very strongly. This much can be said: the lion does not attack man unless when old, toothless, and manged, in which case he is unable to capture his natural prey. The same is to be said of the tiger. The bear seldom attacks man unless when cornered, wounded, or, from some cause, rendered desperate.

The lion, tiger, and bear are possessed of prodigious strength. The two former can kill and carry off a good-sized ox. Nothing comes amiss to them if they are hungry. The lion will attack a buffalo, horse, zebra, wild ass, giraffe, the largest antelopes, and even elephants; and the tiger takes whatever comes in its way in the shape of large and even small game. The wild pig is a favourite meal with both. They prefer living, healthy game in the open, but are not averse to a well-fed, dead carcase if judiciously placed in their way. It is not an uncommon thing to tether a live donkey, calf, goat, or even a large dog in the vicinity of their haunts; the hunters concealing themselves in trees until the big game appears, and they get a few tolerably certain shots. Their opportunity comes during the night or early morning. Both lions and tigers are exceedingly dangerous when wounded, and some harrowing tales are told of men who have incautiously followed the wounded animals into the bush, where they have not unfrequently lost their own lives. A dreadful account was given a short time ago in the public prints of a party of engineers engaged in constructing a railway line in South Africa, who endeavoured to shoot lions during the night from a railway carriage. The lions appeared in force, and one of them entered the railway carriage by one window, seized one of the sportsmen, and disappeared with him through another window. He was never again seen or heard of. This was certainly a bold, intrepid act on the part of a lion, which was probably neither shot at nor wounded. An old resident in India on one occasion told me that it was quite a common thing for coolies in that country to be carried off by tigers. The coolies cultivate small patches of rice near the jungle. The tigers come prowling round, and when they see a man at work by himself they pounce upon him and give him one smart blow on the head with one of their powerful paws, and instantly fracture his skull. He is then dragged into a neighbouring thicket, and is numbered with the lost and is no more heard of. It is not an unfrequent thing in India for the tigers to attack the elephants employed in a big game hunt, and with fatal results to some of the party engaged.

Lions and tigers are exceedingly wary animals, and it is very difficult to trap them; in this they give proof of their intelligence. They are most frequently taken in deep pits dug near watering-places and in paths they are known to frequent. The pits are craftily covered over with a thin layer of branches, grass, and leaves, which gives way under their weight.

The watering-places are the scenes of many ferocious fights between lions, tigers, rhinoceroses, hippopotami, elephants, buffaloes, crocodiles, &c.

The lions and tigers are specially courageous when defending their young, for which they show a very laudable affection.

The grizzly bear is an ugly customer to encounter if he be wounded, cornered, or hungry. He is an ungainly, ferocious brute, but does not attack man unless under exceptional circumstances. All the bears are exceedingly crafty animals, and it is next to impossible to circumvent them. They avoid gins of all kinds. Such of them as

are carnivorous secure their prey more by cunning and stealth than by speed of foot. The white or Arctic bear lives chiefly on seals, and these it secures at the blow-holes of the polar seas when the seals come up to breathe. They spend most of their time in the vicinity of the blow-holes near their quarry. In hunting the white bear, the hunters, if possible, secure the young bears, if there are any, and so make tolerably sure of the old ones, which are greatly attached to them. This is not a mode of hunting to be extolled or commended. Affection is, or should be, a sacred trust in men and animals alike.

The great carnivora are best known in a state of confinement; there being few zoological gardens or menageries which cannot boast of a lion, tiger, and bear. The lion in confinement, when cleanly kept and well fed, is a magnificent creature. The male lion may also be said to be magnanimous. He is more restful than the female, and, both in the standing and crouching positions, is the very embodiment of strength, resource, and daring. His roar is tremendous, and literally shakes the earth. His fine mane, rich tawny colour, powerful limbs and claws, formidable mouth, well-knit body, and fiery eyes strike every beholder, and inspire a feeling of awe. His reserve power reminds one of the lightning behind the cloud. He is trustful in confinement, and purrs away to his keeper, who pets him and confides in him in turn.

The old lion-keeper in the Zoological Gardens of London (William Cocksedge by name) simply worshipped his great charge (Rufus), and, as was frequently remarked, acquired a leonine expression—in the same way that old married people, however different their faces, come to resemble each other, particularly when they are married young and their features are plastic. I myself can testify to the facial resemblance of the lion and his keeper. Wombwell's famous menagerie could boast of some splendid lions—one of them named "Wallace," after the Scottish hero. Lions not unfrequently breed in captivity—a fact which at once speaks for their docility and their power of being educated and trained to accept a new state of things. I have examined and studied the Zoological Gardens, London, lions; the Wombwell menagerie lions, and those at Barcelona (Spain); Jardin des Plantes, Paris; Cimiez near Nice, Basle (Switzerland), Hamburg and Berlin (Germany). I was fortunate enough to see a pair of young lions at rut at Berlin in 1872, and a more extraordinary spectacle of passion and power could not possibly be conceived. The male trembled like an aspen leaf, and his eyes literally belched forth fire in his excitement. His roar was ever and anon simply terrible.

Lions have been taught to take part in various performances, but much of their docility is due to the presence and frequent application of the heavily loaded riding-whip. Even with this terror, like the sword of Damocles, hanging over them, they not unfrequently revolt, and, when they do, the life of the so-called lion-tamer is in great jeopardy.

The tigers are less to be trusted than the lions. They are eternally on the prowl in their cages, and have a sinister expression which bodes no good to any one. They are seldom made pets of, and it is never safe to approach their cages too closely. If visitors make this mistake, it is not an uncommon thing for the tigers to suddenly thrust one of their forefeet, with its formidable complement of sharp, curved claws, from beneath the lower bar of the cage in the hope of seizing and lacerating.

The finest tigers I have ever seen were in the Zoological Gardens of Edinburgh (Scotland). They were royal Bengal tigers, supplied by old East India men to the Scottish capital. They were in magnificent condition—very large, and splendidly marked. They were veritable things of beauty, both as regards their long, soft, sleek, striped hides, and the remarkable grace and celerity of their movements. The tigers, like the domestic cats, are incapable of any great depth of affection, and become attached to places rather than to persons. They are considerably less docile and teachable than the lions.

The bears in captivity behave, as a rule, rather well. In a bear pit with its vertical branched pole, the brown bears amuse themselves and the spectators to good purpose. They move about quietly and deftly, and extract numerous buns and other good things from the children. If by any chance a keeper or visitor overbalances and falls into the bear pit, he is promptly, and sometimes dangerously, hugged.

The so-called travelling bears can be taught to perform a great many antics. They are docile to quite a remarkable extent, and are led about on chains by their keepers. The savage nature, however, is apt to crop up on little provocation. They are largely kept in subordination by the frequent use of the keeper's stick. The white or polar bears are less docile but more intelligent than the brown bears. They are reserved and shy, and spend a good deal of their time in the baths attached to their cages. They are, nevertheless, thoughtful, resourceful animals. Captain Scoresby thus writes of the white bear in his "Account of the Arctic Regions": "The animal with two cubs was being pursued by a party of sailors over an ice-field. She urged her young to an increase of speed by running before them, turning round, and manifesting, by a peculiar action and voice, her anxiety for their progress; but finding that her pursuers were gaining upon them, she carried, or pushed, or pitched them alternately forward, until she effected their escape. In throwing them before her, the little creatures placed themselves across her path

to receive the impulse ; and when projected some yards in advance, they ran onwards until she overtook them, when they alternately adjusted themselves for a second throw."

A still more remarkable example of intelligence in the polar bear is recorded by Mr. S. J. Hutchinson. He says : "One Sunday, at the 'Zoo,' some one threw a bun to the bears, but it fell in the water in the quadrant-shaped pond beside them. The bun fell just at the angle, and the bear seemed disinclined to enter the water, but stood on the edge of the pond, and commenced *stirring* the water with its paw, so that it established a sort of rotatory current, which eventually brought the bun within reach. When one leg got tired it used the other, but in the same direction. I watched the whole performance with the greatest interest myself."

Further light will be thrown on the intelligence of the great felines when that of the domestic dog and cat is discussed in succeeding sections.

§ 275. The Intelligence of the Otter.

This is one of the few wild animals which are still to be found in Great Britain and Ireland. It is especially plentiful in the latter country, where the rivers are numerous, deep, sluggish, and well wooded. It affords exceedingly good sport when hunted with a scratch pack of otter-hounds. An otter hunt is exhilarating in the extreme, and those who take part in it are, as a rule, very enthusiastic. It usually comes off in the early morning, when the scent is fresh and strong, and when bush, brake, and meadow are sparkling with dew. The sun—that glorious orb of day—is revealing his newborn splendours, and everybody is buoyant, jocose, and happy. The huntsman, resplendent in red coat and with barely clad limbs and vaulting-pole, is jubilant and big with expectation. The otter-hounds, newly cast off, are darting hither and thither with commendable zeal, their keen noses directed towards the ground in search of an otter trail. Half an hour has been so spent when lo ! the pack suddenly breaks into what is essentially triumphant music. They have found the object of their search, and are instantly in full cry. No one who has heard the deep baying of the otter-hounds can ever forget it. The soft, low, rich voices of the dogs incant a veritable hymn to the morning, and literally make the welkin ring. The field soon catches the infection of the chase, and immediately young and old are vigorously on the move on either bank of the river. A scene of intense excitement follows. I had the good fortune on one occasion to hunt the river Urrin, County Wexford, Ireland, with Major Hill's pack. The sport was inimitable. The otter, a fine old male, was located, after a short run, in a long, rather narrow, deep pool, with alders on either bank. The time and the place were alike propitious. The otter was seen occasionally under either bank. More frequently he remained invisible, but his whereabouts was indicated either by the baying of the dogs or by the straight line of air-bubbles which rose to the surface of the water as he darted up and down, and across stream. It seemed as if a speedy kill was assured. After three-quarters of an hour of this stimulating and exciting practice, the otter utterly and mysteriously disappeared. The huntsman, the dogs, and the entire field were at fault. What had happened was this. The otter, sorely beset by his numerous enemies, had exercised all the ingenuity and cunning he possessed, and made a final and desperate effort at escape. At the lower end of the pool where we were excitedly engaged was a narrow, deep mill-race, and along this the otter stealthily and cleverly swam, not once raising his head, so as to leave no scent. His whereabouts when he came up to blow was accidentally discovered by some agricultural labourers, who headed him back into the pool, from which he had so deftly withdrawn. The tactics adopted by him in the pool were repeated. He was pursued on either bank by the dogs when he came up to breathe, and the line of air-bubbles, as before, revealed his path when he dived and swam under the surface. Again he disappeared, and more mysteriously than at first. Major Hill, not to be denied, got into the pool nearly to the armpits, and with his vaulting-pole probed its left bank until he found the mouth of a drain opening under water. He shouted "Eureka !" in a clear, loud, triumphant voice, which thrilled every one present. The field was again on the *qui vive*, and satisfaction was depicted on every face. The otter had unwittingly entered into a death-trap. An armful of alder bushes was quickly handed to the major, and with these he effectually plugged the mouth of the offending drain. The rest was easy. The drain was tapped high up on the bank of the river, and a second and considerable opening made between the tapped portion and the mouth of the drain. The drain was stopped below the second opening, on the side next the river, and an old master hound judiciously placed at the second opening to keep watch and ward, as it was expected the otter would endeavour to effect his escape at that point ; and so it turned out. These preliminaries over, a copious supply of water was poured into the highest opening of the drain. Instantly the old hound gave tongue. The water had carried the scent of the otter to the hound in waiting. Around him all the other hounds speedily assembled, and a scene of intense excitement and confusion ensued. What with the cheering of the field and the baying of the dogs a very babel of sound followed. Fresh and liberal contributions of water being poured into the upper opening of the drain caused the otter to bolt, as was expected, at the second hole. In the twinkling of

an eye he was at the mercy of the pack, and the spectacle presented was that of a living, excited, angry, moving mass, in which only glimpses of the poor otter could be seen. He was literally torn to pieces, and eaten rump and stump. The dogs were in due time called off and quieted as far as that was possible. After a short, well-earned rest a fresh start was made higher up the river, and with equal success. Within a quarter of a mile from where the kill took place a second otter was discovered. The dogs were soon again in full cry, and succeeded in forcing the otter from a hole in the bank into a long, winding pool, and then into a rapid, where it was seized and speedily despatched. The second otter proved to be a dam, and the huntsman in this case whipped off the hounds and secured the trophies of the chase.

These two successful runs only occupied some three hours, but during the period in question the nerve tension was something phenomenal.

Few animals can compare with the otter for the secrecy of its movements. These are so well planned and so quietly carried out that otters, in many cases, abound where they are not even suspected. They glide into and out of the water without causing the slightest commotion or the faintest sound. I had striking and convincing proof of this a few years ago on a stretch of salmon river rented by me on the Slaney, Ireland. One of the best pools yielded no fish for two years. I looked about in vain for an adequate cause. It gradually dawned upon me that the pool was infested by otters. I got my ghillie to set the necessary traps, and in less than two months he killed five splendid otters. The pool in question, now dubbed the "otter pool," is, at present, the best in the river. Salmon will not rest or take a fly or other bait in a pool infested by otters. These cunning and intelligent animals destroy much more fish than they require for food. They often content themselves with a few hasty mouthfuls from the shoulder of even a big salmon.

The otter is capable of being trained and taught to catch fish for its master—facts indicating a considerable degree of intelligence.

Dr. Goldsmith remarks: "I have seen an otter go to a gentleman's pond at word of command, drive the fish into a corner, and, seizing upon the largest of the whole, bring it off in its mouth to his master."

Other observers testify in the same direction.

§ 276. The Intelligence of the Wolf, Jackal, and Fox.

These three animals virtually belong to the same family, and may be considered together. The two first hunt in packs, and in this they differ from the last. Like other beasts of the chase, they are endowed with exceedingly good brains. The wolf is one of the oldest known animals historically. It was an object of veneration to the ancient Egyptians, who mummified it in large numbers, and frequently depicted it on their temples, tombs, mural tablets, &c. Curiously enough, as I can testify from personal observation, the dogs of Egypt at the present day greatly resemble the wolf in limb and feature. This is more especially true of the shape of the head and muzzle. The wolf was also much revered by the ancient Romans. Indeed they trace in some measure the foundation of their great empire to this animal. According to them, a she-wolf suckled Romulus and Remus, the twin brothers, who ultimately became the fathers of the Roman state. If the legend be true, it furnishes a remarkable example of sagacity and affection on the part of a naturally very savage animal.

The jackal, sometimes called the "lion's provider," is credited with a keen, scrutinising prescience which enables it to take a comprehensive view of things, and to act with despatch. It is believed by many to guide the lion to its prey; its reward being the remains of the feast when the lion has gorged himself.

The fox, of all living quadrupeds, is one of the wisest, most sagacious, and resourceful. "Cunning as a fox" is an adage universally accepted.

Many thrilling stories of wolves pressed by hunger are narrated. Taken separately, wolves are skulking, cowardly creatures. In the pack they are in the highest degree formidable and dangerous. In severe winters in Russia and elsewhere, when natural food is scarce, they band together and attack flocks, homesteads, and men, indiscriminately. In such cases their onslaught is often irresistible. Their great numbers, and the frenzied fury of their attack, carry everything before them. When maddened with hunger they attack fearlessly, and while the attack may cost the pack a great number of lives, they press on until they have accomplished their end and appeased their appetites. The dead wolves form part of the universal feast. It is no uncommon thing for a few wolves to hunt and destroy horses and cattle, and to carry off large numbers of sheep. Their hunting in packs displays a very considerable amount of intelligence. They have fully realised that numbers mean power in a wolf hunt.

Mr. E. C. Buck,[1] on the authority of his friend Mr. Elliot, gives the following example of sagacity in wolves: "He saw two wolves standing together, and shortly after noticing them was surprised to see one of them lie down

[1] *Nature*, vol. viii., p. 303.

in a ditch, and the other walk away over the open plain. He watched the latter, which deliberately went to the far side of a herd of antelopes standing in the plain, and drove them, as a sheep-dog would a flock of sheep, to the very spot where his companion lay in ambush. As the antelopes crossed the ditch, the concealed wolf jumped up, seized a doe, and was joined by his colleague."

Mr. H. Reeks, in a letter to Mr. Darwin, the substance of which is given by Mr. Romanes in his "Animal Intelligence" (p. 436), states that "the wolves of Newfoundland adopt exactly the same tactics for the capture of deer in winter as that which is adopted by the hunters. That is to say, some of the pack secrete themselves in one or more of the *leeward* deer-paths in the forest or 'belting,' while one or two wolves make a circuit round the herd of deer to windward. The herd invariably retreats by one of its accustomed runs, and 'it rarely happens . . . that the wolves do not manage by this stratagem to secure a doe or young stag.' And Leroy, in his book on 'Animal Intelligence,' narrates closely similar facts of the wolves of Europe as having fallen within his own observation."

The famous Dr. Rae, the Arctic traveller, who took a most intelligent interest in wild animals, and whom I knew personally, avers that "wolves have been frequently known to take the bait from a gun without injury to themselves, by first cutting the line of communication between the two." He adds "that wolves watch the fishermen who set lines in deep water for trout, through holes in the ice on Lake Superior, and very soon after the man has left, the wolf goes up to the place, takes hold of the stick which is placed across the hole and attached to the line, trots off with it along the ice until the bait is brought to the surface, then returns and eats the bait and the fish, if any happens to be on the hook. The trout of Lake Superior are very large, and the baits are of a size in proportion."

Wolves and dogs have many traits in common. Both are emotional, and bay the moon; are affected by musical sounds; are social; act singly and in concert. Their actions are rational, and cannot be explained by so-called "instinct" or by "collective instinct," whatever that may mean.

The jackals are quite as intelligent in their way as the wolves. Sir E. Tennent[1] gives the following remarkable account of their tactics in securing food: "At dark and after nightfall, a pack of jackals, having watched a hare or a small deer take refuge in one of these retreats, immediately surrounded it on all sides; and having stationed a few to watch the path by which the game entered, the leader commences the attack by raising the cry peculiar to their race, and which resembles the sound 'Okkay' loudly and rapidly repeated. The whole party then rush into the jungle and drive out the victim, which generally falls into the ambush previously laid to entrap it.

"A native gentleman, who had favourable opportunities of observing the movements of these animals, informed me that when a jackal has brought down his game and killed it, his first impulse is to hide it in the nearest jungle, whence he issues with an air of easy indifference to observe whether anything more powerful than himself may be at hand, from which he might encounter the risk of being despoiled of his capture. If the coast be clear he returns to the concealed carcase and carries it away, followed by his companions. But if a man be in sight, or any other animal to be avoided, my informant has seen the jackal seize a cocoa-nut husk in his mouth, or any similar substance, and fly at full speed, as if eager to carry off his pretended prize, returning for the real booty at some more convenient season."

Mr. Romanes,[2] on the authority of a friend, thus speaks of the Indian jackal: "This gentleman was waiting in a tree to shoot tigers as they came to drink at a large lake, skirted by a dense jungle, when about midnight a large axis deer emerged from the latter and went to the water's edge. Then it stopped and sniffed the air in the direction of the jungle, as if suspecting the presence of an enemy; apparently satisfied, however, it began to drink, and continued to do so for a most inordinate length of time. When literally swollen with water it turned to go into the jungle, but was met on its extreme edge by a jackal, which, with a sharp yelp, turned it again into the open. The deer seemed much startled, and ran along the shore for some distance, when it again attempted to enter the jungle, but was again met and driven back in the same manner. The night being calm, my friend could hear this process being repeated time after time—the yelps becoming successively fainter and fainter in the distance, until they became wholly inaudible. The stratagem thus employed was sufficiently evident. The lake having a long narrow shore intervening between it and the jungle, the jackals formed themselves into line along it while concealed within the extreme edge of the cover, and waited until the deer was water-logged. Their prey, being thus rendered heavy and short-winded, would fall an easy victim if induced to run sufficiently far, that is, if prevented from entering the jungle. . . . A native servant who accompanied my friend told him that this was a stratagem habitually employed by the jackals in that place, and that they hunted in sufficient numbers 'to leave nothing but the bones.'"

These examples of concerted action on the part of wolves and jackals clearly prove their possession of reasoning powers.

[1] "Natural History of Ceylon," p. 35.

[2] "Animal Intelligence," London, 1898, p. 434.

The foxes, in some respects, reason more accurately than either the wolves or the jackals. This is proved by the narratives of the following trustworthy observers.

Mr. Crehore[1] says: "Some years since, while hunting in Northern Michigan, I tried with the aid of a professional trapper to entrap a fox who made nightly visits to a spot where the entrails of a deer had been thrown. Although we tried every expedient that suggested itself to us we were unsuccessful, and, what seemed very singular, we always found the trap sprung. My companion insisted that the animal dug beneath it, and putting his paw beneath the jaw, pushed down the pan with safety to himself; but though the appearance seemed to confirm it, I could hardly credit his explanation. This year, in another locality of the same region, an old and experienced trapper assured me of its correctness, and said in confirmation that he had several times caught them, after they had made two or three successful attempts to spring the trap, by the simple expedient of setting it upside down, when of course the act of undermining and touching the pan would bring the paw within the grasp of the jaws."

Mr. Couch, in his "Illustrations of Instinct" (p. 175), writes as follows: "Whenever a cat is tempted by the bait, and caught in a fox-trap, Reynard is at hand to devour the bait and the cat too, and fearlessly approaches an instrument which the fox must know cannot *then* do it any harm." This authority adds: "Derham quotes Olaus in his account of Norway as having himself witnessed the fact of a fox dropping his tail among the rocks on the sea-shore to catch the crabs below, and hauling up and devouring such as laid hold of it."

Mr. St. John, in his "Wild Sports of the Highlands," gives the following remarkable example of reasoning power in the fox. He says: "When living in Ross-shire I went out one morning in July, before daybreak, to endeavour to shoot a stag, which had been complained of very much by an adjoining farmer, as having done great damage to his crops. Just after it was daylight I saw a large fox coming quietly along the edge of the plantation in which I was concealed. He looked with great care over the turf wall into the field, and seemed to long to get hold of some hares that were feeding in it, but apparently knew that he had no chance of catching one by dint of running. After considering a short time he seemed to have formed his plans, and having examined the different gaps in the wall by which the hares might be supposed to go in and out, he fixed upon the one that seemed the most frequented, and laid himself down close to it in an attitude like a cat watching a mouse. Cunning as he was, he was too intent on his own hunting to be aware that I was within twenty yards of him with a loaded rifle, and able to watch every movement that he made. I was much amazed to see the fellow so completely outwitted, and kept my rifle ready to shoot him if he found me out and attempted to escape. In the meantime I watched all his plans. He first with great silence and care scraped a small hollow in the ground, throwing up the sand as a kind of screen between his hiding-place and the hares' mews; every now and then, however, he stopped to listen, and sometimes to take a most cautious look into the field; when he had done this he laid himself down in a convenient position for springing upon his prey, and remained perfectly motionless with the exception of an occasional reconnoitre of the feeding hares. When the sun began to rise, they came one by one from the field to the cover of the plantation; three had already come in without passing by his ambush; one of them came within twenty yards of him, but he made no movement beyond crouching still more closely to the ground. Presently two came directly towards him; though he did not venture to look up, I saw by an involuntary motion of his ears that those quick organs had already warned him of their approach. The two hares came through the gap together, and the fox, springing with the quickness of lightning, caught one and killed her immediately; he then lifted up his booty and was carrying it off like a retriever, when my rifle-ball stopped his course by passing through his backbone, and I went up and despatched him."

Mr. Jesse narrates the following:[2] "Part of this rocky ground was on the side of a very high hill, which was not accessible for a sportsman, and from which both hares and foxes took their way in the evening to the plain below. There were two channels or gullies made by the rains, leading from these rocks to the lower ground. Near one of these channels, the sportsman in question, and his attendant, stationed themselves one evening in hopes of being able to shoot some hares. They had not been long there, when they observed a fox coming down the gully, and followed by another. After playing together for some time, one of the foxes concealed himself under a large stone or rock, which was at the bottom of the channel, and the other returned to the rocks. He soon, however, came back, chasing a hare before him. As the hare was passing the stone where the first fox had concealed himself, he tried to seize her by a sudden spring, but missed his aim. The chasing fox then came up, and finding that his expected prey had escaped, through the want of skill in his associate, he fell upon him, and they both fought with so much animosity, that the parties who had been watching their proceedings came up, and destroyed them both."

One of the most extraordinary ruses adopted by a fox to attain its ends was told me lately by a friend. Some wild duck were quietly feeding in a river with copse and sedges near. The fox crept stealthily to the river side

[1] *Nature*, vol. xxi., p. 132.

[2] Romanes' "Animal Intelligence," p. 433.

and reconnoitred. As the place where the ducks were was too open to admit of his advance without being seen, he had recourse to the following strategy. He crouched very low, and cautiously wended his way up stream until well above the ducks. He then detached sedges and dry moss from the bank, which he caused to float down stream upon and near the ducks. As they were not alarmed and did not fly away he dexterously slipped into the river with a tuft of sedges in his mouth, and floating gently down secured the best of them.

The depredations of the fox in the poultry yard are too well known to require recital. Nothing short of a lock and key can preserve the henwife's treasures.

The fox, in the wild state, is one of the fiercest of animals, and bites viciously at whatever comes within reach. He can only be handled safely by an expert. I had proof of this on a run with the famous Fifeshire fox-hounds with the renowned Colonel Anstruther Thomson as master. Reynard, a big dog-fox, took earth shortly after the hounds were laid on. The "sappers and miners" of the hunt were instructed to dig him out. This they speedily did. He had gone into a narrow hole where he had no room to turn, and the first portion of him disclosed was his brush. This was seized, and then his body; latterly he was caught firmly by the scruff of the neck. When lifted out of the hole his eyes, a greeny grey, literally glared with rage and malice, and he did his utmost to bite his captors. He was cautiously transferred to a bag, carried to a considerable distance, liberated and given law. He rewarded the field for the delay occasioned, and gave it a brilliant run of an hour and a half. Reynard was in turn rewarded, as he finally escaped.

The following anecdote, told by Mr. Murray Browne, illustrates the savage nature and wonderful sagacity and wisdom of the fox. He says:[1] "I once, at the Devil's Glen, Wicklow, found a fox fast in a trap by the foot. We did not like to touch him, but got sticks and poked at the trap till we got it open. The process took ten minutes or a quarter of an hour. When first we came up the fox strained to get free, and looked frightfully savage; but we had not poked at the trap more than a very short time before the whole expression of his face changed. He lay perfectly quiet (though we must at times have hurt him); and when at last we had got the trap completely off his foot, he still lay quiet, and looked calmly at us, as if he knew we were friends. In fact, we had some little difficulty in getting him to move away, which he did readily enough when he chose. Was not this a case of reason and good sense *overpowering* natural instinct?"

The white or Arctic fox is quite as cautious and far-seeing as his brown congener.

Dr. Rae gives the subjoined interesting details:[2] "When trapping foxes in Hudson's Bay it sometimes happens that certain of these acute animals, probably from having seen their companions caught, studiously avoid the ordinary steel and wooden traps, however carefully set. The trapper then sets one or more guns in a peculiar manner, having a line fifteen or twenty yards long uniting the trigger with a bait, on taking hold of which the fox sets the gun off, and commits suicide. The double object of the bait being placed so near the gun is that the fox may be certainly killed—not wounded only—and that the head alone should be hit, and the body not riddled all over with shot, which would spoil the skin. It is also necessary to mention that four or five inches of slack line must be allowed for contraction of the line by change from a dry to a moist atmosphere, which otherwise would cause so great a strain on the trigger that the gun would be discharged without the bait being touched. So as to conceal as far as possible all connection between bait and gun, that part of the line next the bait is carefully hid under the snow.

"When the fox takes the bait, he will have lifted it five inches (the length of the slack line) from its normal position before the gun goes off; consequently, instead of pointing the gun at the bait, it is aimed fully eight or nine inches higher, at the probable position of the brain of the animal when the gun is discharged.

"For reasons which scarcely require explanation, foxes very generally go about in pairs (long before the snow disappears), not necessarily always close together, because they have a better chance of finding food if separated some distance from each other.

"After one or more foxes have been shot, the trapper, on visiting his guns, perhaps finds that a fox has first cut the line connecting the bait with the gun, and then gone up and eaten the bait; or, if the gun has been set on a drift bank of snow, he or she has scraped a trench ten or twelve inches deep up to the bait, taken hold of it whilst lying in the trench, set the gun off, and then trotted coolly away with the food (taken, one may say, from the gun's mouth) safe and uninjured, as is clearly evinced by there being no mark of blood on the tracks.

"In the cases seen by myself, and by a friend of greater experience, the trench was always scraped at right angles, or nearly so, to the line of fire of the gun. This at first sight may appear erroneous, but on reflection it really is not so, for if the trench is to be a shelter one—thinking, as the fox must have done, that the gun or something coming from it was the danger to be protected from or guarded against—it must be made across the

[1] Op. cit., p. 431.

[2] Op. cit., pp. 430, 431.

line of fire, for if scratched in the direction of fire, it would afford little or no protection or concealment, and the reasoning power or intelligence of the fox would be at fault.

"My belief is that one of these knowing foxes had seen his or her companion shot, or found it dead shortly after it had been killed, and not unnaturally attributed the cause of the mishap to the only strange thing it saw near, namely, the gun.

"It was evident that in all cases they had studied the situation carefully, as was sufficiently shown by their tracks in the snow, which indicated their extremely cautious approach when either the string-cutting or trench-making dodge was resorted to, in attempting to obtain the coveted bait without injury to themselves."

It is not necessary to pursue the subject further. Enough, it appears to me, has been said to establish beyond doubt a reasoning faculty in wolves, jackals, and foxes. It is not possible to explain their actions by such loose terms and phrases as so-called instinct, collective instinct, inherited habit, &c. Such terms and phrases have, in reality, no scientific value.

§ 277. The Intelligence of the Weasel, Ferret, and Polecat.

These three animals possess so much in common that time will be saved by considering them together.

The weasel is one of the most ferocious and determined little creatures in existence. His boldness, considering his size, amounts to impertinence. He faces and turns upon animals ten and even twenty times his own size and weight. I remember when a boy endeavouring to trample one to death in long grass. He showed fight, and squeaked fiercely. When I pressed him he disappeared in the grass, and his agility and rapidity of movements were such that do my best I could not trample upon him. On the "Links" at Elie, Fifeshire, Scotland, I observed, some years ago, two weasels and a newly killed rabbit at the mouth of a rabbit burrow. I advanced towards the trio, stick in hand. To my utter surprise the weasels did not retire into the burrow. On the contrary, they showed unmistakable signs of fight: they exposed their teeth in an angry way, squeaked, and leapt into the air within a couple of yards of me. They did not disappear until I applied my stick to them boomerang fashion. As already stated in a previous section of this work, I have seen a weasel chase a rabbit to death. The pet aversion of the weasel is the rat, and endless fights occur between the two.

The ferret, which is considerably larger than the weasel, can always out-manœuvre and kill a rat. At Wakefield Asylum, Yorkshire, England, where rats are numerous and very large, I took part in many rat hunts, and rat and ferret fights. When a rat and a ferret are put into a cage together hostilities at once begin. The mode of attack and the finish are always the same. The ferret takes the initiative. He thrusts his head forward at the rat, and the rat squats on his haunches and attempts to parry the thrust of the ferret with its fore-legs and feet. The ferret persists in his thrusts, which, in reality are only so many feints to worry and fatigue the rat. The movements of the ferret when so engaged are snake-like in their ease, sinuosity, and rapidity. After a few minutes the rat is exhausted and outwitted, and entirely at the mercy of the ferret. The ferret makes one final thrust, and seizes the rat behind and above the ear, and in a moment all is over. I have seen a dozen or more rats so killed.

It is not a little remarkable that both the weasel and the ferret exhaust their quarry by strategy, and deliver their final attack on the head or back of the neck when they can get at these parts. Their mode of attack has method and intelligence in it. Seeing they attack and kill animals much larger than themselves, it follows that they must resort to modes of "fence" with which they are familiar, and which are unknown to the animals on which they prey. The long, narrow bodies and sinuous, lithe movements of weasels and ferrets give them a decided advantage over larger and more unwieldy animals. Their determined pluck and known ferocity also seem to strike terror into the birds and beasts with which they come in contact.

The ferret can be readily tamed, and taught to hunt rats and rabbits. He is very docile, in a way, but bites at once if alarmed or rudely handled. He is best muzzled when rabbiting. If left unmuzzled the chances are he gets hold of a young rabbit in a burrow, kills it, and has a square meal. Under these circumstances he naturally falls asleep, to the disgust of the gunners. An hour or two of precious time may be so wasted if other ferrets are not forthcoming. A good muzzled ferret goes about his work very expeditiously and thoroughly. He knows exactly what is expected of him, and causes the rabbits to bolt in every direction. When hunting in a large burrow he occasionally appears for a moment or two at the mouth of a hole, and, if not picked up or called to, he at once disappears and continues his operations.

The tact, strategy, and indomitable energy of weasels and ferrets bespeak remarkable powers, and these animals display much reasoning ability.

Mr. Thompson, in his "Passions of Animals" (p. 337), represents Mdlle. de Faister describing her tame weasel to Buffon as playing with her fingers "like a kitten, jumping on her head and neck; and if she presented her hands

at the distance of three feet, jumping into them without ever missing. Distinguishing her voice amidst twenty people, and springing over everybody to get at her. She found it impossible to open a drawer or a box, or even to look at a paper, without his examining it also. If she took up a paper or book, and looked attentively at it, the weasel immediately ran upon her hand, and surveyed with an inquisitive air whatever she happened to hold."

Mr. Romanes relates that he once kept a ferret as a domestic pet.[1] "He was a very large one, and my sister taught him a number of tricks, such as begging for food (which he did quite as well and patiently as any terrier), leaping over sticks, &c. He became a very affectionate animal, delighting much in being petted, and following like a dog when taken out for a walk. He would, however, only follow those persons whom he well knew. That his memory was exceedingly good was shown by the fact that after an absence of many months, during which he was never required to beg, or to perform any of his tricks, he went through all his paces perfectly the first time that we again tried him."

Professor Alison, in his article on "Instinct," [2] quotes the following regarding polecats from the *Magazine of Natural History*: "I dug out five young polecats, comfortably embedded in dry, withered grass; and in a side hole, of proper dimensions for such a larder, I picked out forty large frogs and two toads, all alive, but merely capable of sprawling a little. On examination, I found that the whole number, toads and all, had been purposely and dexterously bitten through the brain."

§ 278. The Intelligence of the Wolverine or Glutton.

This is comparatively an unknown animal, but its intelligence, caution, and cunning are phenomenal. It is, as its name indicates, a rapacious, greedy feeder, and gives endless trouble to trappers. The following account of its habits and its depredations is furnished by Dr. John Rae, F.R.S., the Arctic traveller, in a letter to Mr. Romanes. He says (p. 348): "They are very suspicious, and can seldom or never be taken with poisoned bait, trap, or gun. The poisoned baits are usually found broken up, but not eaten by them; traps are destroyed or entered, but not where the trapper desired; and guns, except when concealed after the Eskimo fashion by a covering of snow, are avoided.

"In 1853, on the Arctic coast, when about to change our domicile from a tent to the warmer snow hut, my man had carried over about 100 lbs. or more of fine venison steaks to the snow-houses about a quarter of a mile from our tents; and as there were at the time no traces either of foxes, wolves, or wolverines about, the meat was placed overnight in one of the huts, and the door left open. During the night two wolverines came, but, evidently dreading some trap or danger in the open door, would not enter that way, but cut a hole for themselves through the wall of the snow hut, and carried off all our fine steaks, a considerable quantity of which was picked up close to our house when the thaw took place in the spring, it having been hid in the snow, but completely spoilt for use, by a well-known filthy habit."

The above is supplemented by Captain Elliot Coues and by Mr. Ross, who write as follows:[3] "To the trapper the wolverines are equally annoying. When they have discovered a line of marten traps they will never abandon the road, and must be killed before the trapping can be successfully carried on. Beginning at one end, they proceed from trap to trap along the whole line, pulling them successfully to pieces, and taking out the baits from behind. When they can eat no more, they continue to steal the baits and *câche* them. If hungry they may devour two or three of the martens they find captured, the remainder being carried off and hidden in the snow at a considerable distance. The work of demolition goes on as fast as the traps can be renewed.

"The propensity to steal and hide things is one of the strongest traits of the wolverine. To such an extent is it developed that the animal will often secrete articles of no possible use to itself. Besides the wanton destruction of marten traps, it will carry off the sticks and hide them at a distance, apparently in sheer malice." Mr. Ross adds: "At Peel's River, on one occasion, a very old carcajou discovered my marten road, on which I had nearly a hundred and fifty traps. I was in the habit of visiting the line about once a fortnight, but the beast fell into the way of coming oftener than I did, to my great annoyance and vexation. I determined to put a stop to his thieving and his life together, cost what it might. So I made six strong traps at as many different points, and also set three steel traps. For three weeks I tried my best to catch the beast without success; and my worst enemy would allow that I am no green hand in these matters. The animal carefully avoided the traps set for his own benefit, and seemed to be taking more delight than ever in demolishing my marten traps and eating the martens, scattering the poles in every direction, and *câching* what baits or martens he did not devour on the spot. As we had no poison in those days, I next set a gun on the bank of a little lake. The gun was concealed in some low bushes, but the

[1] Romanes' "Animal Intelligence," p. 347.
[2] Todd's "Cyclopædia of Anatomy," p. 206.
[3] From Romanes' "Animal Intelligence," pp. 348, 349.

bait was so placed that the carcajou must see it on his way up the bank. I blockaded my path to the gun with a small pine tree, which completely hid it. On my first visit afterwards I found that the beast had gone up to the bait and smelled it, but had left it untouched. He had next pulled up the pine tree that blocked the path, and gone around the gun and cut the line which connected the bait with the trigger, just behind the muzzle. Then he had gone back and pulled the bait away, and carried it out on the lake, where he lay down and devoured it at his leisure. There I found my string. I could scarcely believe that all this had been done designedly, for it seemed that faculties fully on a par with human reason would be required for such an exploit if done intentionally. I therefore rearranged things, tying the string where it had been bitten. But the result was exactly the same for three successive occasions, as I could plainly see by the footprints ; and what is most singular of all, each time the brute was careful to cut the line a little back of where it had been tied before, as if actually reasoning with himself that even the knots might be some new device of mine, and therefore a source of hidden danger he would prudently avoid. I came to the conclusion that that carcajou ought to live, as he must be something at least human, if not worse. I gave it up, and abandoned the road for a period."

§ 279. The Intelligence of the Rat.

This is one of the best known, and, at the same time, one of the most sagacious, resourceful, and thoughtful of animals. It is also foreseeing and prescient to an extraordinary degree. Originally found in the open, like other wild animals, it has for centuries dogged civilisation, and become a pest of the first magnitude. Its association with human dwellings, and the granaries and food supplies generally of the genus *homo*, has apparently quickened its wits, and it contrives, somehow, to house itself comfortably, and to secure a little of the best of everything in season and out of season. It even goes to sea in his Majesty's ships so long as they are seaworthy, but leaves them at the first opportunity when they show signs of leaking, and when they are worn out and dangerous. Its whole conduct is that of a reasoning creature, which acts deliberately and after due consideration ; which takes all the facts of a case into account, and judges and decides what is best to do under the circumstances. Not only does it secure its daily food but it stores up and provides an adequate supply for the exigencies of winter. In the country I have again and again come across its hoards of provisions. Its larder is found in the most out-of-the-way places, and pretty well contains everything : vegetables and grains of all kinds, eggs, scraps of bacon, dried fish, bits of cheese, bread, biscuit, &c., &c.

I was particularly struck with its blackmailing propensities in the summer of 1904 in a fine old garden in County Wexford, Ireland. This garden is famous for its strawberries, and, as the yield was not equal to that of the previous year, I was induced to make a personal inspection of the strawberry beds. To my chagrin, and, I may add, disgust, I found that the rats, which have greatly increased of late years, had literally stripped the plants of nearly all their fruit, and this I found piled up in little round heaps ready to be carried to their holes. They had collected the unripe as well as the ripe fruit—no doubt intending to eat the ripe fruit first. Rats are not content with mere outdoor supplies. They invade human dwellings from the palace to the hovel, and their modes of tapping the larders thereof and the contents of the larders are ingenious and clever to a degree. Their thieving powers are equal to, and even surpass, those of first-class burglars. They first scrape and cut their way through the foundations of the house to be plundered. When once an entrance is effected they swarm all over it, and find their way to everything edible. It is a mere question of time ; nothing short of a locked metal safe can keep them out. The more food lying about the greater their number. They rarely or never enter a trap, and avoid poisoned food with a skill truly marvellous. They do nothing in a careless, haphazard way. They take advantage of every nook which promises safety, and even avail themselves of the presence of shadows in their efforts at escape. They can abstract oil, preserves, and other fluid and semi-fluid substances from bottles and jars with narrow necks into which they could not possibly introduce their heads. They can also carry off and secrete full-sized hen's eggs. These feats at first sight seem impossible, but the explanation is simple when once known. The rats eat through the bladder or paper, or pull out the cotton wool stopping the bottles and jars, and thrust their long tails well into the contents : they then withdraw their tails, smeared all over with the coveted fluid, which they lick off themselves or give their fellows to lick. In stealing eggs one rat lies on its back and receives the egg between its fore and hind legs ; it is then drawn, chariot fashion, by a team of rats to the place of concealment. Rats have been known to convey eggs down and even up stairs. In the removal of eggs two or more rats take part. If the eggs are to be taken to a rat granary on the same level, they arrange themselves in a row and pass the eggs from the one to the other by means of their fore-paws. If the eggs are to be transported downstairs two rats at least are required. In this case, the rat on an upper step passes the egg down to its fellow on the step below ; the rats alternately changing places.

If the eggs are to be carried upstairs one rat balances itself on its fore-legs and passes the egg up on its hind-legs to its fellow on the step above. Dr. Carpenter in the *Quarterly Review* thus explains the process: "The male rat places himself on his fore-paws, with his head downwards, and raising up his hind-legs and catching the egg between them, pushes it up to the female, who stands on the step above, and secures it with her fore-paws till he jumps up to her; and this process is repeated from step to step till the top is reached."

Rats, under certain circumstances, are exceedingly courageous and bold. I have seen a rat fasten himself to the nose of a terrier dog, from which he could not be shaken until the dog was rendered sick from pain and shock, when the rat let go and escaped. Instances have been known where rats banded together and attacked miners in pits where, from some cause or other, their food ran short; this is especially the case where the pits have been closed for longer or shorter intervals. It has happened from time to time that rats have attacked children in their cradles, and adults in their sleep.

While ferocious when pressed by hunger, rats are very docile, gentle, and affectionate, as a rule. It is no uncommon thing for a blind rat to be led about and fed by others which are in possession of all their senses. Rats also take the field against a common enemy.

The intelligence displayed by rats in getting into dwelling-houses and at their food supplies is truly wonderful. They burrow, in many cases, long distances to effect an entrance, and when they encounter an obstacle they either remove it or work a passage round it. Once in the house, they cut holes and make passages in all directions. Every kind of woodwork disappears before them, and lead, zinc, and other pipes and fittings are often gnawed through. They are especially severe on the timbers of ships, and, in the olden time, before iron and steel vessels were built, the hulls of wooden ships were in a measure cut to pieces. Curiously enough, the rats had the sagacity never actually to cut holes through the sides or bottoms of the ships. They always stopped short of actual perforation. More wonderful still, they deserted the ships thus destroyed by themselves when they reached port. In modern times rats still infest vessels, but their ravages are confined to internal fittings; the iron and steel hulls being proof against them. The multifarious doings of rats cannot be explained by so-called instinct, which, according to those who employ the term, requires a set of unvarying conditions and the possession of habits supposed to be transmitted. The rats (and this is the most wonderful thing) adapt themselves to new and altogether novel conditions, so that their acts cannot, in any sense, be regarded as involuntary or automatic. They are, in nine cases out of ten, voluntary, rational acts. The operations of the rat prove beyond doubt that intelligence is not confined to man, and that the animals share it with him in greater or lesser measure.

It is difficult to say whether animals improve or deteriorate under domestication. The rule, I think, may be laid down that the wild strain is purer, more intellectual, and more resourceful than the civilised or artificial strain. This follows because wild animals have to find their own living, to protect themselves from their natural enemies, and to find suitable shelter; whereas tame animals are supplied with food, protected from enemies, and comfortably housed with no effort on their part. The necessity for exercising and developing brain, always present in wild animals, is, to a large extent, absent in tame animals. Certainly the domestic ox is on a lower intellectual level than the buffalo and bison, and similar remarks are to be made regarding the domestic sheep, goat, and pig as compared with the wild sheep, goat, and pig. On the other hand, there are animals which seem to benefit intellectually from associating with man, such as the horse, ass, elephant, cat, dog, and monkey. There is this to be said, that the latter animals are more closely associated with man than the former, and, from being constantly under his influence, have apparently come to participate in part in his intellectuality.

This seems to hold true more especially of the horse, ass, dog, elephant, and monkey.

§ 280. The Intelligence of the Ox.

The intellect of this most useful domestic animal cannot be rated very high. It is, as a rule, gentle and patient, and lends itself ungrudgingly to the demands of the husbandman in the matter of milk and agricultural labour. When employed as a beast of burden, its kindly disposition and great strength make it an invaluable auxiliary. It is equally serviceable in the waggon and in the plough, and is much employed in the East. As an article of food it cannot be excelled or indeed equalled. The different members of the bovine race have their peculiarities, but into them it is not necessary to enter.

The cattle of our own islands are characterised by great symmetry and beauty of form, the result of careful interbreeding extending over long periods. In the fields they browse peacefully and quietly, and are in no sense aggressive. The bulls occasionally assume an offensive attitude, but this largely arises from jealousy, and from a fear of any one interfering with the cows. Cattle are affectionate and emotional. This is seen in the great

regard they have for their calves, especially when permitted to suckle them, and in the effect which instrumental music has upon them. I have seen a whole field of these animals thrown into a great state of excitement by the music of a country band. The cattle followed the music, and, raising their tails high in the air, ran helter-skelter, bellowing as they did so. Cattle are also exceedingly curious. If anything unusual is placed in the field in which they are grazing, they immediately collect round the strange object and view it from all points of the compass. I have on more than one occasion when fishing had my rod thrown down by these inquisitive creatures, when, after a long spell of casting, I had incautiously set it against a tree to enjoy a brief rest.

Cattle detest dogs, and mob and pursue them as soon as they enter the field where they are feeding. Their feeling of hostility is no doubt caused by the recollection of the dogs snapping at their heels.

Cattle are sympathetic, as well as affectionate, emotional, and curious. If one of their number be bogged or injured, they at once assemble and bellow, and become more or less excited. On such occasions, they show unmistakable signs of anxiety, pain, and distress. In bygone times, it used to be the custom to bleed young cattle in the field in the spring. I very well remember the perturbation produced in the herd by the bleeding operation. The veterinary surgeon had scarcely commenced his work when the herd snorted and stampeded. The sight and smell of the blood seemed to drive them mad. Similar scenes are witnessed in slaughterhouses and their vicinity.

Mr. Robert Hamilton thus writes of the ox in the slaughterhouse: "The animal witnessing the process of killing, flaying, &c., repeated on one after another of its fellows, gets to comprehend to the full extent the dreadful ordeal, and as it mentally grasps the meaning of it all, the increasing horror depicted in its condition can be clearly seen. Of course some portray it much more vividly than others; the varying intelligence manifested in this respect is only another link which knits them in oneness with the human family."

I have myself seen similar feelings produced in pigs when being slaughtered one by one from a pen. When two or three had been killed, and the remaining pigs in the pen had seen and smelt the blood, they became restive, and squealed at intervals. They also made for the back of the pen—the part furthest removed from the scene of action. As each pig was taken from the pen it struggled violently and endeavoured to escape. When fairly confronted with its fate, the expression of its face suddenly changed, and its skin blanched and became visibly paler—a result, no doubt, due to uncontrollable fear. All the pigs behaved similarly when their turn came.

To the other attributes of the domestic ox there can be added a certain amount of pride. In Switzerland it delights in the tinkle of the bells attached to its neck. It also follows its leader, whose bell has a different tone from its own. Schiller in his "Wilhelm Tell" says:—

> "See with what pride your steer his garland wears;
> He knows himself the leader of the herd;
> But strip him of it, and he'd die of grief."

The ancient Egyptians held "bulls" in the highest estimation. They were regarded as the emblems of strength and courage. Not only did they worship and sedulously feed and pet them during their lives, but they mummified them after death, and provided them with magnificent granite and other sarcophagi.

The Serapeum, or "Mausoleum of the Bulls," is scarcely less imposing than the "Tombs of the Kings" themselves. I confess to having experienced a feeling of awe when I entered for the first time the huge galleries in which the sacred bulls repose. These galleries are on such a vast and magnificent scale that one cannot help admiring the people who devoted their time and substance to the carrying out of great ideas—distorted and barren though these ideas doubtless were. I have always greatly approved of the attention paid to all kinds of animals by the ancient Egyptians. While animals are not to be regarded as sacred objects, they are nevertheless fully entitled to all the attention and kindness we can bestow upon them.

The Serapeum is thus described by M. Brodrick and A. A. Morton in their "Egyptian Archæology" (1902): "The huge vaults opened by Mariette consist of three parts, one which originally contained the bulls of the period from Amen-hetep III. to the XXth Dynasty, another those of XXIInd to XXVth Dynasties, and the third part those from the reign of Psammetichus I. (XXVIth Dynasty) to the time of the later Ptolemies. Thus the burials cover a period of about 1450 years, that is, from about 1500 B.C. to about 50 B.C.

"Only the third part is open to the public, the two first being covered with sand. This part consists of one long gallery excavated in the rock, and some shorter ones. On either side of the long gallery are deep pits in which are the enormous sarcophagi. These are monoliths of red or black granite, or limestone, the average measurements being—length 13 ft., width 8 ft., height 11 ft."

The bull was one of the earliest animals worshipped by the ancient Egyptians, and it has been depicted in various attitudes with great force and accuracy on the bas-reliefs of Egyptian temples, tombs, stelæ, &c. It has also been represented with great fidelity in innumerable pieces of sculpture; some of them being colossal, some life-size, some half life-size, and others smaller and smaller in a decreasing scale until only a few inches long.

§ 281. The Intelligence of the Sheep.

This is the most timid and gentle of all the domestic animals. It is gregarious, and less intelligent than the ox, with which it has been associated from time immemorial. The probability is that it figured as a domestic animal even before the ox. The ancient Egyptians had a ram-headed god (Khnemu or Khnem) "worshipped chiefly at Philæ, where he is represented as making mankind out of clay upon a potter's wheel. His name signifies the Moulder" ("Small Egyptian Dictionary," p. 85). At hundred-gated Thebes they had magnificent avenues of colossal ram-headed sphinxes conducting to their temples. One of these avenues is a mile and a quarter long. These sphinxes are marvellous works of art. I have carefully examined some of the best preserved specimens, *in situ*, and am free to confess that finer representations of rams' heads cannot be conceived. They are perfect in all their details—even to the texture of the skin and the hair. The expression of the eyes, and of the face generally, is very striking. The most fastidious critic would have no difficulty in recognising in these subtle masterpieces of ancient art the familiar lineaments of a well-bred modern ram. The ram and the bull do not seem to have changed in the least for five or six thousand years. The same is true of all the animals depicted with such amazing accuracy and force on the ancient Egyptian temples, tombs, sarcophagi, slabs (stelæ), papyri, &c. The persistency of type revealed and guaranteed by ancient Egyptian animals, and the absolute identity of the animals with modern living specimens, deal a heavy blow to the theory of evolution. If animals can descend from parents to offspring in unbroken succession for six or more thousand years, without even a shadow of change, it goes far to prove that the types are separate original creations, and not modifications of each other or of one primal type.

Those who believe in evolution will, of course, say that six or more thousand years is but a drop in the great ocean of time. This is, however, evading the point at issue. They should be able to show, geologically or otherwise, progressive changes in the bull, ram, and the other animals so faithfully depicted by the ancient Egyptian limners and sculptors. They should be able to trace back the several animals to predecessors differing considerably from the present stock. This they admittedly cannot do. They can advance no positive evidence of a direct character in support of their contention. It is a question of direct positive evidence, which can be weighed as in a balance, versus indirect negative evidence, which is intangible and illusory. The doctrine of evolution rests on a purely theoretical basis, and ought not to be accepted as a tenet in modern science. It is unworthy of a place even as a working hypothesis.

The present digression on type provoked by my allusion to the "sacred bulls," "the Egyptian ram-headed god," and "the ram-headed sphinxes," will, I hope, be pardoned considering the very great interest which has always attached to cattle and sheep in relation to man as a civilised being.

The sheep, even more than the ox, has been a stand-by to all the early peoples. In Bible times it represented the wealth of the patriarchs and their numerous descendants. It has provided milk, flesh meat, clothing, carpets, &c., to untold generations of men, and is as useful to-day as it was at the dawn of history. While no great degree of intelligence can be claimed for the sheep, it nevertheless possesses many valuable traits of character. It is inoffensive and amiable, it is affectionate and attentive to its offspring, it becomes exceedingly tame and trusting, it is easily fed and housed, it has no great tendency to stray, it follows the "bell-wether" or a human master, it offers no resistance when its fleece is required for clothing or its flesh for food. It is absolutely the slave of man at all stages of its existence.

Similar remarks may be made of the ram. He, however, at certain seasons, and when old, shows a good deal of temper, and is aggressive. A butting ram is at once formidable and dangerous, and many cases are recorded of people having been knocked down and seriously injured by him. Sheep are eminently social, and are unhappy when separated from the flock. This induces them to follow a leader and each other whatever the consequences. If one breaks away and leaps into a river or over a precipice all the others follow. Only the shepherd, and the shepherd's dog, can save them from a blind confidence in each other. Their intelligence is of a passive rather than an active kind.

§ 282. The Intelligence of the Goat.

The goat is superior in intelligence to either the ox or the sheep. This is largely due to its mode of life. While the ox and sheep browse on rich level pastures, the goat seeks his food in mountainous districts, where crags and precipices abound, and where vegetation is scarce and not of the best. The goat is consequently always scheming how he is to overcome obstacles in obtaining a bare livelihood. Necessity, as the adage goes, is the mother of invention, and the wits of the goat are constantly at work. Increase of function leads to increase of brain substance, and the result is a higher intelligence.

The goat is a daring, highly resourceful animal, and picks up a living where most other herbivora would starve. The ibex, chamois, and other members of the family are famous for the perilous leaps made by them when hunted, and even when quietly grazing in their favourite haunts. On these occasions, they sometimes land on their horns and yet contrive not to break their necks or injure themselves in any way.

On one occasion I made a careful study of the habits and movements of the chamois through a powerful telescope on the high mountains in the vicinity of the Rosegg glacier, Pontresina, Switzerland. It was very delightful to watch those nimble, strong, elegant animals playing with each other, nibbling at hill shrubs, bounding from crag to crag with a precision and lightness truly astounding. Their spring was so elastic and airy that they might have been birds. Secure in their lofty Alpine peaks from all danger, they wandered about unconcernedly and contentedly, and seemed as tame as antelopes or fallow deer in a home park. Their every position and action was graceful. It mattered not whether they were lying, standing, walking, trotting, racing, or leaping. Each position and movement had its own peculiar charm, and was to me fascinating in the highest degree. It is seldom one is privileged to see wild animals in their native haunts and under such favourable circumstances.

The goat in captivity is docile to a degree, and submits to be tethered and its movements confined to a small patch of grass, which it patiently and contentedly crops. This says a great deal for its intelligence, for it is, naturally, the freest of free animals. In Italy, Switzerland, and other countries where it is reared, it is led out in flocks to rock pastures in the early morning, and returns in the evening to yield its rich milk to the expectant owner. In such cases, the goats of one peasant join the goats of another peasant in village or hamlet at a given hour in the morning until a large herd is collected under a common goat-herd, who conducts them to desirable pasturage and superintends them during the day. In the evening, when the herd returns to be milked, it is most interesting to see the several goats of the herd drop off and leave the herd when they reach their owner's house. This they do of their own accord, and apart from directions given by any one.

Considering the nature of the ground on which goats feed, it happens not unfrequently that the animals find themselves in dangerous situations and in tight places, from which it is exceedingly difficult to extricate themselves. On such occasions they display a great deliberative power, a fine judgment, and rare courage. They never lose their heads. The more difficult the situation the greater the intelligence displayed. A not uncommon occurrence is for two goats to meet on a narrow mountain ridge with a precipice or steep gorge on either side. The goats cannot pass each other, and cannot possibly recede as there is no room to turn. Under these circumstances the goats look at each other earnestly and thoughtfully for some time, until they have mentally discussed matters and come to a common finding. One of the goats then kneels, and lies down very cautiously. This done the other walks deliberately and fearlessly over the prostrate form of his fellow. The apparently impossible situation is successfully negotiated, and both goats are free to pursue the even tenor of their way, which they composedly do. The state of things here set forth is attested by numerous observers, in various countries, so that implicit belief on the part of the reader should not be withheld. The following remarkable example of intelligence on the part of the goat is recorded in "Mrs. Lee's Anecdotes" (p. 366): "A goat and her kids frequented a square in which I once lived, and were often fed by myself and servants—a circumstance which would have made no impression, had I not heard a thumping at the hall door, which arose from the buttings of the goat when the food was not forthcoming, and whose example was followed by the two little kids. After a time this remained unheeded, and, to our great astonishment, one day the area bell used by the tradespeople, the wire of which passed by the side of one of the railings, was sounded. The cook answered it, but no one was there save the goat and her kids, with their heads bent down towards the kitchen window. It was thought that some boy had rung for them; but they were watched, and the old goat was seen to hook one of her horns into the wire and pull it. This is too much like reason to be ascribed to mere instinct."

Mrs. Lee's discrimination between "reason" and "instinct," shown in the last passage of the above quotation, is deserving of much commendation, considering the laxity which prevails in the employment of two words which have admittedly very different meanings. The ringing of a door-bell would not be considered an instinctive act on the part of a man, neither can it be so considered on the part of a goat. In either case it is voluntary and rational.

While goats, like sheep, are naturally docile, peaceful creatures, it happens, ever and anon, that the male or "billy-goat," which is usually provided with large, powerful horns, is aggressive and fierce. He is even a more formidable butter than the ram, and, as he is a much more active animal, he is consequently more dangerous. I remember when a boy witnessing a fierce encounter between a billy-goat and a large sheep-dog. The dog made persistent attacks on the goat's heels, but the goat's movements were so rapid and dexterous that the dog did not once succeed in biting his opponent. If afforded me great amusement to watch the goat turning round and round,

as on a pivot, and always receiving the dog with lowered head and horns in a position to impale him. The battle, though stubborn, was a drawn one. The goat eluded the charge of the dog, and when the goat charged, which it did frequently, the dog in turn eluded the charge of the goat.

§ 283. The Intelligence of the Horse.

Of all the domestic animals the horse is, in some senses, the finest. As regards form it is unquestionably the most handsome. It is also the fleetest. It is, next to the elephant, the most powerful. It is courageous, mild tempered, and docile, and a fit companion for man in all quarters of the globe. The Arab horse, as I have seen it in Africa, Turkey, Spain, and other countries, is a very dream among animals. Its lovely small head, flowing mane, finely arched, abundant tail, well knit, symmetrical body, and elegant, powerful limbs place it on a pedestal among animals. Add to this its high courage and amiable disposition, and its willingness and pride in serving man, and you have a complete picture of a perfect animal. The Arab horses are at once the companions of the fierce Arab chiefs and of their children, who at times play between their legs when the animals are standing, and climb over them when reclining. The finest Arab horses I have seen are in the stables of the Sultan of Turkey. They are perfect models in every way, and splendidly groomed and caparisoned.

The horse is naturally a high-spirited, nervous, intelligent animal. When carefully trained and kindly treated there is scarcely anything it will not attempt or accomplish. In the circus and hippodrome it will thread its way, even amidst fire, and perform the most extraordinary feats. In the hunting field it will tackle with pasture and ploughed land, with mountain and plain, with copse and woodland, with river and lake, and take all kinds of fences and impossible jumps. In war it faces all sorts of unusual sights, and is not dismayed with the terrible roar of artillery and other frightful sounds.

The horse has supreme confidence in its master, and, if the master be thoughtful, resourceful, and cool, the horse seldom fails him in time of need. If the horse at any time falls short, it is, for the most part, the fault not of the animal but of the man. It no doubt occasionally happens that an underbred, imperfectly trained, badly ridden or badly driven horse shies, bolts, and injures itself and everything with which it comes in contact. This is, fortunately, the exception and not the rule. Horses are generally what men make them. They are, when well bred and properly trained and treated, gentle, confiding, and utterly to be relied on. When underbred, improperly trained, and harshly treated, they are tricky, vicious, and apt to be violent and dangerous. Their great strength is both for and against them. When properly directed and employed it is an invaluable available power; when improperly directed and employed it is a standing menace and danger. Having driven and ridden a good deal in my youth, I have no hesitation in stating my belief that the horse is in complete sympathy with his master, both in the saddle and in the shafts. It is extraordinary how quickly the horse distinguishes between the male and female hand in riding and driving. Some horses, which are perfectly tractable when ridden or driven by a man, become skittish and unmanageable if ridden or driven by a woman. The horse is quick to perceive and acknowledge the power of the stronger sex: it is not always amenable to the discipline of the gentler sex.

The horse can be trained to take part in all kinds of games, evolutions, and pageants, and is obviously proud of the figure it cuts on such occasions. It delights in the chase, fox-hunting, pig-sticking, &c.; it eagerly takes part in all military drills, manœuvres, and combinations; it conducts itself with equal propriety at festal and mournful ceremonies, and is an outstanding object in all kinds of processions and pageants. Its versatility in accommodating itself to the most varied situations—many of them new and strange—is traceable to its intellect and great power of adaptation. Horses trained in particular directions come to be largely self-directed; they do their work with or without a master. War horses are frequently guided less by the reins than by the knees of their riders, and the same is true of polo ponies. The utility and value of the horse to man consists in its ready obedience, and its power of realising what is expected of it. This bespeaks a large measure of intelligence. It is one thing to obey, but quite another thing to know what obedience means, and the ends to be served by obedience.

The horse is emotional as well as high-spirited and nervous. It is also affectionate. The feelings of a horse may be played upon to almost any extent by coaxing and petting. Its love for its young is beautiful to behold. The gallantry of the stallion towards the mare recalls the palmy days of chivalry. I have seen an entire horse lick the neck of a mare in the most endearing fashion, and literally win her affection. This noble creature is full of emulation, and not a little jealous of rivals. It delights in gay trappings almost as much as a lady in fine dresses. Its one desire seems to be to stand well in the eyes of its owner. All its best qualities are evoked by judicious, kindly, firm treatment: all its worst ones by foolish, harsh, inconsistent treatment.

The so-called taming of horses as practised by Mr. Rarey and others is a cruel and senseless proceeding. Breaking the spirit of a horse, and frightening it to death, is not training in the proper sense. Mr. Rarey took

vicious, unmanageable horses, hobbled them, tied up their legs, and threw them on the ground in a helpless condition. He then beat drums, and made all sorts of frightful noises in their ears. He also made free with their bodies, and touched all parts of them. The animals were outraged, stupefied, and frightened out of their wits. He also sat upon and took the most extraordinary liberties with them. Neither their intelligence nor their feelings were taken into account. It was a case of wanton outrage pure and simple. A horse cowed and "broken in" in this fashion could never be a staunch, reliable animal. It was apt to resort to its vicious habits, and, when opportunity served, make the most of them. An adult horse suddenly trained by force is quite another animal from a young horse slowly trained by suasion and petting. The horse, in the former case, obeys blindly from a sense of fear: in the latter case it acts from a sense of duty, and is proud so to act. In the one case, the horse merely exercises its brute force: in the other, it exercises that force, plus intellect.

No doubt a horse thoroughly frightened, from whatever cause, is an absolutely unmanageable and dangerous animal. A runaway horse is a terror to gods and men—its prodigious strength and speed making it grievously injure itself and everything with which it comes in contact. In almost all cases of fright in horses there is carelessness, stupidity, or worse, on the part of the persons in charge. Horses rarely bolt or run away if the individuals attending them are present and do not lose their heads. A few words of encouragement or a little stroking and petting generally get over the difficulty. The attendants, as a rule, are more to blame than the horses they are supposed to care for and control.

All horses are intelligent, but some are more so than others. It is the less intelligent ones which, for the most part, get into trouble. The Spanish guides, in selecting a mule for dangerous mountain passes, recommend not the strongest or fleetest, but the one with the best head. A similar selection should be made in horses.

The great speed of the horse indicates immense nerve energy and muscular force, and a concomitant degree of brain-power. No animal with the speed of the horse could get along safely with a small brain and a feeble nervous system. The effect of early training is very noticeable in the after life of the horse. The late Professor Fleming (Moral Philosophy in the University of Glasgow) told me of a gin horse which went in a circle from left to right six days a week, but on the seventh, or day of rest, he went in an opposite circle, from right to left. He released and rested his muscles not by lying down or rolling as other horses do when at grass in the field, but by a direct counter movement.

At the conclusion of the great American war, a very large number of British cavalry horses had to be abandoned owing to the impossibility of transportation. When the officers and men were seen departing in boats, the horses appeared greatly distressed. Subsequently they seemed excited and maddened, and forming themselves into battalions they fiercely charged each other, with the result that after each charge a large number were left dead on the field.

Many anecdotes are told of the sagacity and reasoning power of the horse tribe. I quote a few of them as given by Mr. Romanes in his "Animal Intelligence" (pp. 330–33). He says: "I myself had a horse which was very clever at slipping his halter after he knew that the coachman was in bed. He would then draw out the two sticks in the pipe of the oat-bin, so as to let all the oats run down from the bin above upon the stable floor. Of course he must have observed that this was the manner in which the coachman obtained the oats, and desiring to obtain them, did what he had observed to be required. Similarly, on other occasions he used to turn the water-tap to obtain a drink, and pull the window cord to open the window on hot nights."

He relates how a Mr. W. J. Fleming had a vicious horse "which, while being groomed, frequently used to throw a ball of wood attached to his halter at the groom. He did so by flexing his fetlock and jamming the ball between the pastern and the leg, then throwing the ball backwards 'with great force.'"

The following is from the *Orkney Herald*: "A well-authenticated and extraordinary case of the sagacity of the Shetland pony has just come under our notice. A year or two ago Mr. William Sinclair, pupil teacher, Holm, imported one of these little animals from Shetland on which to ride to and from school, his residence being at a considerable distance from the school buildings. Up to that time the animal had been unshod, but some time afterwards Mr. Sinclair had it shod by Mr. Pratt, the parish blacksmith. The other day Mr. Pratt, whose smithy is a long distance from Mr. Sinclair's house, saw the pony, without halter or anything upon it, walking up to where he was working. Thinking the animal had strayed from home, he drove it off, throwing stones after the beast to make it run homewards. This had the desired effect for a short time; but Mr. Pratt had only got fairly at work once more in the smithy when the pony's head again made its appearance at the door. On proceeding a second time outside to drive the pony away, Mr. Pratt, with a blacksmith's instinct, took a look at the pony's feet, when he observed that one of its shoes had been lost. Having made a shoe he put it on, and then waited to see what the animal would do. For a moment it looked at the blacksmith, as if asking whether he was done, then pawed once

or twice to see if the newly-shod foot was comfortable, and finally gave a pleased neigh, erected its head, and started homewards at a brisk trot."

Mr. Samuel Goodbehere, solicitor, Birmingham, is responsible for the subjoined narrative: "We had a Welsh cob pony or Galloway about fourteen hands high, who was occasionally kept in a shed (in a farmyard), partly closed by the front of a gate, which was secured by a bolt inside and a drop latch outside. The pony (who was able to put his head and neck over the gate, but could not reach the outside latch) was constantly found loose in the yard, which was considered quite a mystery until it was solved one day by my observing the pony first pushing back the inside bolt, and then neighing until a donkey, who had the run of the yard and an adjoining paddock, came and pushed up the outside latch with his nose, thus letting the pony at liberty, when the two marched off together."

Mr. Strickland, in a communication to *Nature* (vol. xix., p. 410), says: "A mare here had her first foal when she was ten or twelve years old. She was blind of one eye. The result was, she frequently trod upon the foal or knocked it over when it happened to be on the blind side of her, in consequence of which the foal died when it was three or four months old. The next year she had another foal, and we fully expected the result would be the same. But no; from the day it was born she never moved in the stall without looking round to see where the foal was, and she never trod upon it or injured it in any way."

The most careful treatment of the second foal was doubtless due to experience, memory, and judgment. So-called instinct could have no place in such a case.

The following remarkable example of sagacity and reasoning in a mule is given by Professor Nipher, of Washington University, St. Louis, U.S.: "A friend of mine living at Iowa City had a mule, whose ingenuity in getting into mischief was more than ordinarily remarkable. This animal had a great liking for the company of an oat-bin, and lost no opportunity, when the yard gate and barn door were open, to secure a mouthful of oats. Finally the mule was found in the barn in the morning, and for a long time it was impossible to discover how he had come there. This went on for some time, until the animal was 'caught in the act.' It was found that he had learned how to open the gate, reaching over the fence to lift the latch, and that he then effectually mystified his master by turning round and backing against it until it was latched. He then proceeded to the barn door, and pulling out the pin which held the door, it swung open of its own accord."

It would be easy greatly to increase the number of anecdotes illustrating the possession of intelligence by the horse and its congeners, but sufficient have been given to establish beyond doubt the existence of a reasoning faculty in this most admired and extraordinarily useful animal.

§ 284. The Intelligence of the Cat.

The cat has largely profited by its long connection with man, although not to the same extent as the dog. This is due to its shallower, less sympathetic, less emotional nature. It attaches itself more to places and things than to individuals, and returns to a state of nature on slight provocation. It is quite a common thing for a cat in the full enjoyment of the luxuries of civilisation to desert its home temporarily, or permanently, and take to the fields and woods and live upon game, which it waylays and catches. Its own comforts and enjoyments are always first in its estimation. With the exception of catching mice and rats it does no service for man. It is far otherwise with the dog, which hunts for his amusement, drives sheep and cattle, draws sledges and small carts, watches and defends houses, performs mechanical work of various kinds, &c.

The chief occupation of the cat consists in hunting for its own amusement and profit. It hunts alone; it is not a social, gregarious animal, which shares its joys and sorrows with its fellows. It leads a more or less mechanical existence, and does not strike out new paths as the dog does. It is a copyist rather than an inventor, and the extraordinary stories told of its ringing bells and banging door knockers are largely traceable to imitation. It, however, does reason, although not so accurately and to such an extent as the dog. Its affection chiefly centres in its offspring, but there are notable examples where it has been largely transferred to its master or mistress.

Its affections, at best, are limited, and its nature cannot be said to be either magnanimous or generous. Its paws, so soft when retracted, are in reality "mailed fists," and strike with incredible rapidity and poignancy when unsheathed. There is all the difference in the world between a cat contented and purring, and a cat excited and enraged. In the former case, the paws are as soft as velvet, and the claws, as a rule, escape observation: in the latter case, the paws become rigid, and are suddenly armed with menacing rows of sharp, curved, cruel claws, which mangle everything they touch. I have made the acquaintance of both kinds of paws. On one occasion I was the happy possessor of a young, sprightly, playful cat, to which I was greatly attached, and which used to sit on my knee to be stroked and petted; it followed me about everywhere, and we were the best of friends. One afternoon, as was my wont, I strolled into the garden; pussy followed, and in the shrubbery near the gate she caught a hedge-

sparrow, which she brought to me alive. I took her up, and tried to liberate the bird, which she held loosely in her mouth. The moment I tried to relieve her of her prey her eyes glared, she crunched her teeth through her quarry, and dug her sharp-pointed claws with all the energy she possessed into my hands. I was utterly amazed and disgusted with her behaviour, and threw her and her unfortunate captive over the garden wall. Since that unpleasant episode my liking for cats has been considerably modified, and, of late years, I rather taboo them.

Of course it is their nature to hunt and kill, but in addition to this, cats are cruel, and play with and torture their victims before they destroy them. I have again and again witnessed this in the case of mice. Moreover, one is not called upon to love a thing which has an essentially unlovable nature. I shall never forget a great fright I had with a very large, powerful tom cat. My brothers and I had a fine collection of high-priced fancy pigeons, which we kept in a roomy, unfinished attic. The birds gained admittance to it by a small hinged window in the roof which could be opened and closed by means of a ratchet. On going into the attic one morning I found that one of our best birds had just been killed—the blood being still warm and flowing. I felt convinced the murderer must be near, and closed the attic window to prevent escape. I looked up and around but could see nothing; I then looked between the joists of the partially closed floor, when lo! a pair of grey, green, savage eyes met mine. The depredator was an overgrown tabby. I looked about for the weapons of war, and found, after a short search, an old walking-stick with a solid knob as handle at one end. I seized the thin end of the stick, and resolved to fight the cat with the thick knobby end. I drove the culprit from its skulking place, and determined to give battle in the open. The cat at once realised my tactics, and took to the rafters overhead. The agility displayed by it in leaping from rafter to rafter was incredibly great. It literally flew, and I could only once and again deliver an effective blow. I, however, stuck to my work, and in less than ten minutes the murdering thief was dead at my feet. A good many fine pigeons had been killed before by this or other cats, and my blood was up. I have, however, often shuddered to think what might have been the consequences of that hand-to-hand encounter with the large, frightened, enraged feline. It might have leapt upon and torn my head and face fearfully, and attacked me as fiercely as I attacked it. Possibly the knowledge of its wrongdoing saved me. I emerged from the attic victorious, and, as was natural, considerably elated, but I felt then, and have often felt since, that my temerity on the occasion did not at all square with my Scotch caution.

Cats, as is well known, hate the water, yet their love of fish as an article of diet is so great that they occasionally set aside their natural feelings, and patiently sit at a river side until fish appear, when they fearlessly plunge into the water and secure them. Cats and dogs are at natural enmity with each other—hence the phrase "a cat and dog life"; nevertheless, many cases are recorded where cats and dogs have not only tolerated, but have been attached to each other.

The whole life of the cat pretty well centres in its love of offspring and in its hunting propensities. All the rest is to be regarded as thin veneering, which partly conceals and disguises, but never wholly shuts out and excludes, the two ruling passions.

The cat, physically, is one of the fittest of animals. Its symmetry is perfect, and its movements graceful and exact in the extreme. It can walk about amidst rows of delf and glasses without breaking a single one. When so engaged it has its muscular system, which is a highly strung one, under perfect control. Its movements, under the circumstances, more resemble those of a snake than a quadruped. The most beautiful curves and sinuosities are generated in its backbone and tail. These are seen to great advantage when the animal is studied walking, and is observed from above. There is no creature whose movements are more sudden and accurate. It pounces upon its prey like a bolt from the blue, and its aim is so good, and its estimate of distance so just, that it rarely misses the object it attacks. The cat can take tremendous leaps, climb trees, and run at a remarkably high rate of speed. It possesses great daring and courage, and is blessed with extraordinary patience. When engaged in hunting it is as wise and wily as the serpent. To see a cat stalking a bird, and crouching and trailing itself along from bush to bush, until it gets within striking distance, is to witness a great intellectual effort in strategy. It is in such cases that a cat is seen at its best. Every nerve and every muscle is, so to speak, on the stretch. No mistake must be committed; no branch or leaf made to rustle; its eyes have the cunning and fierce malignity of the evil one. If it misses its quarry, which it does occasionally, it exhibits in its face the discontented and disgusted expression which characterises the disappointed intriguer or gambler. The affection of the cat for its young is very marked, and is a redeeming feature in its otherwise not very amiable character. I have seen a litter of young cats which were drowned, and thrown on the dust-heap for dead, rescued, and the major portion of them resuscitated by the mother, to the surprise and even horror of their would-be executioners. It is quite a common thing for cats to remove their progeny from place to place in search of greater privacy or security. A cat with kittens is more than a match for most dogs, and the hen, under similar circumstances, is quite a match for both cat and dog. The maternal instinct in animals practically knows no fear.

The following anecdotes from trustworthy sources will further illustrate the disposition and character of the cat:—

Mr. A. Percy Smith relates how a cat which was punished when her kittens made nasty messes taught her kittens to be cleanly in their habits.

Mr. Blackman tells of a cat which, "whenever it wanted to go out, would come into the sitting-room, and make a peculiar noise to attract attention. Failing that mode being successful, it would pull one's dress with its claw, and then, having succeeded in attracting the desired attention, it would walk to the street door and stop there, making the same cry until let out."

The following is written about a cat belonging to Mr. Meek the palæontologist: "He had fixed upright on his table a small looking-glass, from which he used to draw objects from nature, reversed on wood. The cat, seeing her image in this glass, made several attempts to investigate it, striking at it, &c. Then coming apparently to the conclusion that there was something between her and the other animal, she very slily and cautiously approached it, keeping her eye on it all the while, and struck her paw around behind the mirror, becoming seemingly much surprised at finding nothing there. This was done repeatedly, until she was at last convinced that it was beyond her comprehension, or she lost interest in the matter."

Mr. Romanes [1] relates on the authority of a correspondent the subjoined: "One evening there was no one in the kitchen. Cook had gone upstairs, and left a bowl full of dough to rise by the fire. Shortly after, the cat rushed up after her, mewing, and making what signs she could for her to go down; then she jumped up and seized her apron, and tried to drag her down. As she was in such a state of excitement cook went, and found 'Polly' shrieking, calling out, flapping her wings and struggling violently, 'up to her knees' in dough, and stuck quite fast." He also draws attention to a case narrated by Mr. Hutchings,[2] where a cat caught a young bird and kept it alive and used it as a bait for attracting and securing its parent, the cock bird, which was fluttering about in a great state of excitement and terror. The cat even poked up the young bird with its paw to make it struggle and cry, and so increase the horror of the parent, the intended victim. The snare was set in vain, but the setting of it revealed remarkable reasoning power in the shrewd, designing cat.

Dr. Frost [3] gives even a more striking example of reasoning power in this wily feline. He remarks: "Our servants have been accustomed during the late frost to throw the crumbs remaining from the breakfast table to the birds, and I have several times noticed that our cat used to wait there in ambush, in the expectation of obtaining a hearty meal from one or two of the assembled birds. Now, so far, this circumstance in itself is not an example of abstract reasoning, but to continue. For the last few days this practice of feeding the birds has been left off. The cat, however, with an almost incredible amount of forethought, was observed by myself, together with two other members of the household, to scatter crumbs on the grass with the obvious intention of enticing the birds."

The cat, in common with elephants and monkeys (and dogs in a lesser degree), displays a knowledge of mechanical contrivances. Mr. Romanes in his "Animal Intelligence" (pp. 420, 421) relates that his coachman once had a cat which, certainly without teaching, learnt to open a door that led into the stables from a yard into which looked some of the windows of the house. Proceeding, he says: "Standing at these windows when the cat did not see me, I have many times witnessed her *modus operandi*. Walking up to the door with a most matter-of-course kind of air, she used to spring to the half-hoop handle just below the thumb-latch. Holding on to the bottom of this half-hoop with one fore-paw, she then raised the other to the thumb-piece, and while depressing the latter, finally with her hind-legs scratched and pushed the doorposts so as to open the door."

The cat uses its paws pretty much as a parrot uses its feet, a monkey its hands, and an elephant its trunk. In all these cases there is correlation, and co-ordination of movement between these parts of the body and the brain. They are, *par excellence*, the instruments of the brain. The greater the quantity and the higher the quality of the brain, the more perfect the co-ordination in question. In man the best hands, that is, the cleverest hands, are invariably associated with the best and cleverest brains.

The following anecdotes illustrate the capacity of the cat for banging door knockers and ringing bells:—

Mr. Belshaw thus writes in *Nature* (vol. xix., p. 659): "I was sitting in one of the rooms, the first evening there, and hearing a loud knock at the front door was told not to heed it, as it was only the kitten asking admittance. Not believing it, I watched for myself, and very soon saw the kitten jump on the door, hang on by one leg, and put the other fore-paw right through the knocker and rap twice."

Archbishop Whately relates the following: "This cat lived many years in my mother's family, and its feats of

[1] "Animal Intelligence. International Scientific Series, 7th edition, p. 416. London, 1898.
[2] *Nature*, vol. xii., p. 330.
[3] *Nature*, vol. xix., p. 519.

sagacity were witnessed by her, my sisters, and myself. It was known, not merely once or twice, but habitually, to ring the parlour bell whenever it wished the door to be opened."

The examples quoted above of reasoning power in the cat furnish their own commentary.

§ 285. The Intelligence of the Dog.

Of all the domestic animals the dog has been most intimately associated with man. Theirs is, apparently, an indissoluble union. From the most remote times down to the present they have been fast friends. In ancient times the dog was useful in hunting wild animals for food and in tracking enemies. In recent times, if the cattle and sheepdog be excepted, it is almost exclusively devoted to sport and pleasure. Dogs are sometimes trained to smuggle valuable goods across continental frontiers. The St. Bernard dog is taught to give first aid ; the bloodhound is still occasionally employed in tracking human beings ; and the lurcher is a noted and successful poacher. Other avocations are pursued by the dog according to fashion or the whim of the owner. The number of fancy dogs of late years is legion, and the prices paid for them fabulous. The size of the dog ranges from the great German wolfhound to the tiny Prince Charlie. They vary in form and colour as much as, or more than, pigeons. Their strong points are a reasoning faculty, and their inalienable affection for, and devotion to, man. The bulldog is one of the staunchest of the race ; from him all the hunting and sporting dogs receive the strain of firmness and savagery which fits them for the chase. The staghound, the greyhound, the foxhound, the otterhound, and the harrier all derive the hunting propensity from the amiable but determined individual which boasts a big head, large square-shaped muzzle with powerful teeth, a broad chest, and strong, short, bandy legs. The bulldog is no beauty, but he is very wise, and occasionally his face wears a semi-human expression. Dogs vary in the amount and quality of their intelligence. The big dogs (St. Bernard, mastiff, and Newfoundland) are generally good-natured and magnanimous : the small dogs (terriers, pugs, and diminutive pets of all kinds) are, as a rule, quick-tempered, snappish, and jealous. The St. Bernard and Newfoundland dogs have proved themselves great rescuers of human life. The cattle and sheepdogs have enabled man to manage large herds of cattle and flocks of sheep, especially the latter, which would otherwise have been impossible. A single sheepdog has, unaided, been known to collect and bring to the shepherd in the morning a flock of over two hundred sheep, which had broken away from him the night before. The sheepdog is one of the most knowing and faithful of its kind to its master ; it is, however, apt to be treacherous to strangers. It generally attacks from behind, a habit possibly acquired from snapping at the heels of sheep. One of the greatest surprises and shocks I ever experienced was caused by a sheepdog so attacking me. I had passed the farmhouse in which it was located on my way to a lawn-tennis party in the country, and was unsuspectingly enjoying the fresh air and the scenery ; it stole out and quietly stalked me for four or five hundred yards, and without the slightest warning attacked and lacerated, rather badly, the calf of my leg. Before I could wheel round and give the offender a much-needed kick it was in full retreat with its bushy tail thrust deeply between its hind legs. I have never since trusted a collie dog, and when one now approaches me with loud, baying, open mouth I suddenly stoop down as if to pick up a stone to throw at it. This movement utterly disconcerts the aggressor, and puts it to immediate flight. That small dogs are jealous in the extreme is proved by this. One of my lady friends—a great fancier of dogs—was one afternoon sitting in an armchair with a favourite terrier in her lap ; she was at the same time stroking and petting a large mastiff pup which was sitting beside her. The terrier, in a fit of anger, flew at her face and bit her nose severely. I was sent for to give advice, and I attributed the attack to jealousy and not to rabies, which was a great comfort to the lady and her family.

Many tragic tales are told of the fidelity of dogs. Not long ago (May 1905) a story went the round of the newspapers of a dog whose master was killed on a railway line. It would let no one come near the mutilated remains. Not even an express train could drive it from its self-imposed task of guardian. The train passed over it, fortunately without injury, and, after a time, partly by petting and partly by coercion, it permitted itself to be removed. In like manner, dogs have mourned over departed masters, and would not leave their coffins until they were hid from view in the graveyard. Even then their task of wailing and sorrowing was not ended. They refused to leave the new-made grave, and, for days, remained there, consumed with grief, and denying themselves everything in the shape of food and drink. There are cases of dogs which from grief, affront, or some outrage to their feelings, have pined and died a lingering death. The dog above all other animals appreciates, and is grateful for, attention and kindness. It also feels most acutely neglect, slight, and harsh treatment. In this respect it is almost human. That dogs experience a sense of shame after misconduct, and even in the performance of certain natural functions, I am very fully convinced after long and careful observation. In this opinion I by no means stand alone.

The memory, judgment, and reasoning powers of dogs are strongly attested by the long journeys made by them

when they are lost in distant cities and markets. Under these circumstances dogs find their way home—often across seas—by deliberately availing themselves of all the means of modern travel, namely, tramcars, railways, steamboats, &c.

The dog of the blind man pilots him safely through all kinds of crowded thoroughfares, and, at the same time, collects the coppers on which his master subsists.

The railway porters of the Caledonian Railway (Scotland) had a dog called "Bob" which travelled regularly in the train between Edinburgh and Glasgow for many years, and collected funds for one of their benevolent institutions. Every one knew "Bob," and few failed to give him a copper.

Dogs have a great amount of self-reliance, and work out their own destinies in civilised communities independently and to quite a remarkable extent. They are, however, eminently social, and occasionally work in concert. I knew a collie and a terrier in Linlithgowshire, Scotland, which were sworn friends, and romped and hunted together. It was at once amusing and instructive to watch their proceedings when a hunt was arranged. The terrier stole out quietly and made for a field where rabbits abounded. The collie, after a brief interval, followed suit. Duly arrived at the rendezvous, the two set to work to find the trail of a fresh-run rabbit. This they readily did, and tracked the rabbit to its hole. Now commenced the real work of the joint expedition. The collie vigorously applied his paws and fore legs to the hole, and made the soil fly fast and furious behind him. The terrier, located between his hind legs, in turn removed the accumulations of soil so produced. When the collie was exhausted with scraping and digging, the terrier took his place; the collie playing second fiddle. In this way I have seen the two extract a rabbit from its hole 4 feet long, in a little over a quarter of an hour. These two dogs were inveterate poachers. They were forbidden to hunt, and whipped for so doing, but their tactics were so masterly that they were seldom discovered. They knew perfectly well that they were transgressors. They left the house singly and stealthily, and returned in the same manner. An outsider would have regarded them as strangers, or, at the most, casual acquaintances. If caught on the hill, and not actually engaged in a rabbit hole, they scampered off in different directions and sneaked home, assuming quite an innocent, indifferent air.

Dogs are, in some cases, great dissemblers. They even knowingly and purposely deceive. A common ruse adopted by them, if they are afraid of being kept in the house when their master is going for a walk, is to steal away quietly long before the expected start, and get a half mile or a mile in advance—a distance too great to be turned back, and generally sufficient to reconcile the master to the arrangement.

My late colleague, Professor William Swan of the University of St. Andrews, was frequently tricked in this way by a Skye terrier named Wisp. He had a summer residence at Ardchapel, near Helensburgh, on the estuary of the Clyde, where I used to visit him. When we wished to join a Clyde steamer for an excursion we had to be rowed to the steamer in a small boat. The dog on such occasions was left at home. This distressed the poor animal very much, as he was utterly devoted to the professor. On these occasions it was a matter of life or death as far as the dog was concerned. He suffered the small boat to depart without him, but when it had got well out to sea, he plunged into the sea and followed. There was nothing for it but to wait until the dog overtook the boat and was taken on board. If the small boat, as it did occasionally, pursued a slanting direction along the shore, the dog ran along the shore considerably in advance, and jumped into the sea at a point which would enable him to meet the boat on its arrival. It was very amusing to watch the manœuvres of this wonderful creature. His tactics were equal to those of an old general in the field. The professor was very proud of his canine favourite, and never had the heart to scold or whip him. His conduct in very many ways was that of a human being.

Dogs have remarkable memories. I have a friend, Mr. A. M. Aitken, an English barrister, who spent his professional life in Singapore. He returned at intervals to his native country (Scotland), and had, on the occasion to which I am about to refer, been abroad for six and a half years. He left a Skye terrier, two and a half years old, to which he was greatly attached, at his home (Torphichen) when he departed, and on his return was curious to know whether the dog remembered him. The terrier cautiously approached him and sniffed. He was not satisfied and withdrew. Again he approached, and withdrew. He repeated the operation a third time, and then, to my friend's great delight, he recognised him and leaped up, barked, and exhibited unmistakable signs of great joy.

Dogs have a curious habit of burying their food, and this they exhume frequently at long intervals. They never forget where their tit-bits are secreted. In my own home in Lanarkshire, Scotland, we had a terrier—quite a character in its way—which used to absent itself for a week or ten days ever and anon. On these occasions it led a wild life in the woods, living on whatever it could pick up. On its return from one of these marauding expeditions it was reprimanded and severely beaten. It suddenly disappeared, and was never again heard of. Whether it resented the treatment to which it was subjected, and wilfully deserted our house for good, or sought a new home, or was trapped, we never found out.

I had a great weakness for dogs of the chase before and when I was a student, especially greyhounds, setters,

and pointers, and one or all of them were generally my companions. The setters were my prime favourites, and with these I literally stalked the country wherever there was a bit of moorland or the appearance of heather. Looking back at my early experiences with setters and pointers, I am fully persuaded that their good qualities in the field are largely due to training and experience. The training to which they have been subjected for many generations is essentially intellectual in character; the nerve cells of the brain have been impressed and modified, and the knowledge thus acquired has been transmitted to the young dogs. There is, as a result, mental and physical improvement up to a point. I say up to a point, because improvement in animals (and even in plants) has its limits. There is no such thing as indefinite improvement in any living thing. Beyond a certain point, degeneration generally sets in. This, as history shows, is true not only of plants and animals, but also of men and of nations. Nature provides types in an ascending scale; she also arranges for a certain amount of improvement within the types, and this improvement takes place through atomic and molecular changes in the living things themselves, due to original endowment and tendency, experience, habit, superior food, environment, and, last not least, continuous training in specific directions. A craftsman cannot transmit his craft to his offspring, neither can an animal transmit the experience of its life to a successor, but the improved nerve cells and substances, which result from the craft and the experience, can be transmitted up to a point and within given limits. In no other way can the automatic acts at present classed under "instinct," which, as I have explained in previous sections of this work, are the outcome of experience, reason, and habit, be accounted for.

The well-bred setter points at game before it has any experience or knowledge of the matter in hand. It can only so act because of inherited mental peculiarity and physical fitness.

In stating my views on this much disputed question, I am not ignorant of the opinions entertained by Professor Weismann. He holds strongly that "acquired characters" cannot be transmitted. I object to his doctrine for two reasons: (*a*) it makes improvement in the individual and in the race impossible, and (*b*) it fails to account for the appearance and disappearance in time and space of whole cycles of plants and animals; these admittedly having gradually reached a climax as regards size, form, and function, and then gradually declined.

This holds true of the great extinct plants of the coal measures, and of the extinct mammoth reptiles and monster Nautiloidæ. That all parts of animals, and especially the nervous system, can be modified up to a point by experience, training, habit, association, and environment seems proved by this, that a female animal which has conceived and brought forth young profoundly differs from one which has never conceived or is barren. The changes induced are especially noticeable in the nervous system and disposition. The sympathies of the mother are broadened and quickened. It need only be remarked that it is the nervous system which is more particularly modified and altered by training. As the nervous system, when it exists, dominates all the tissues and organs of the body, it is easy to understand how, if the molecules of the brain be modified and changed, even in the slightest degree, by experience, training, habit, association, and environment, the modifications and changes extend to every molecule of the organism, with the result that new characters are acquired, and, being acquired, are transmitted. Mental traits and physical form are equally the outcome of training, experience, cross breeding, and good food, within limits. These influences will never convert a dog into a horse, or a horse into an elephant, but the dog, horse, and elephant will certainly be improved by their judicious employment up to a point, which point will ultimately be reached. The subject here discussed is not a matter of so-called "natural selection," for, as I have already pointed out, there is no such thing as natural selection where an intelligent breeder is at work. The breeder, and he alone, is the selector. When the breeder is eliminated, the so-called "natural selection" must be attributed to the Creator or First Cause. Plants and animals, as I have frequently pointed out, cannot select and perpetuate what is good in themselves; neither can they suppress what is bad. They have no power to alter their ultimate constitutions. Wherever selection occurs it is the work of the Creator or of the artificial breeder. The selection is, in every instance, outside the plants and animals themselves, and it is from the outside that the so-called "acquired characters" are, for the most part, produced.

There is no domestic animal concerning which so many extraordinary stories may be told as the dog. These are for the most part intellectual in character. I quote a few, from well-known and trustworthy sources.

"Lieutenant-General Sir John H. Lefroy had a terrier which it was the duty of his wife's maid to wash and feed. It was her habit, after calling her mistress in the morning, to go out and milk a goat which was tethered near the house, and give 'Button' the milk. One morning, being rather earlier than usual, instead of going out at once she took up some needlework and began to occupy herself. The dog endeavoured in every possible way to attract her attention and draw her forth, and at last pushed aside the curtain of a closet, and never having been taught to fetch and carry, took between his teeth the cup she habitually used, and brought it to her feet."

"Mr. A. H. Baines had a Pomeranian bitch which, when quite young, used to soak hard biscuits in water till

soft enough to eat. She would carry the biscuit in her mouth to the drinking-trough, drop it in and leave it there for a few minutes, and then fish it out with her paw."

Dr. Beattie relates how a dog near Aberdeen saved its master's life : " The Dee—the largest of the Aberdeenshire rivers—being frozen, a gentleman named Irvine was crossing the ice, which gave way with him about the middle of the river. Having a gun, he was able to keep himself from sinking by placing it across the opening. 'The dog made many fruitless efforts to save his master, and then ran to a neighbouring village, where he saw a man, and with the most significant gestures pulled him by the coat, and prevailed on him to follow. The man arrived on the spot in time to save the gentleman's life.' "

M. Dureau de la Malle gives an account of a terrier born in his house which had never seen a door knocker at home, and which when grown up was taken to Paris. " Getting fatigued by a walk through the streets, the animal returned to the house, but found the door shut, and it endeavoured vainly to attract the attention of those within by barking. At length a visitor called, knocked at the knocker, and gained admittance. The dog observed what had been done, and went in together with the visitor. The same afternoon he went in and out half a dozen times, gaining admittance on each occasion by springing at the knocker."

" Mr. Williams, in his book on 'Dogs and their Ways' (p. 124), says that a friend of his had a collie which, whenever his master said the words 'Cast, cast,' would run off to seek any sheep that might be cast, and on finding it would at once assist it to rise. He also knew of another dog, which would perform the same office even in the absence of his master, going the round of the fields and pastures by himself to right all the sheep that he found to be cast."

The cattle dogs of Cuba [1] are sometimes employed in landing cattle from ships. " The oxen are hoisted out with a sling passing round the base of their horns ; and when an ox, thus suspended by the head, is lowered, and allowed to fall into the water, so that it may swim to land, men sometimes swim by the side of it and guide it, but they have often dogs of this breed which will perform the service equally well, for, catching the perplexed animal by the ears, one on each side, they will force it to swim in the direction of the landing-place, and instantly let go their hold when they feel it touch the ground, as the ox will then naturally walk out of the water by itself."

Lord Brougham, in his " Dialogues on Instinct," relates the following of a dog which was wont to worry and kill sheep overnight : " The animal quietly submitted to be tied up in the evening, but when everybody was asleep he used to slip his collar, worry the sheep, and, returning before dawn, again get into his collar to avoid suspicion."

Mr. Richard Williams, of Buffalo, furnishes additional evidence of the strategy of the sheep-worriers. He remarks : " And here let me ask if you are aware of the cunning and sagacity of these sheep-killing dogs, that they never kill sheep on the farm to which they belong, or in the immediate vicinity, but often go miles away ; that they always return before daylight, and before doing so wash themselves in some stream to get rid of the blood."

The following relates to the wonderful power possessed by dogs of finding their way about and of availing themselves of the facilities of modern travel.

Mr. Horsfall [2] writes as under : " Last year we spent our holidays at Llan Bedr, Merionethshire. Our host has a house in the above village, and another at Harlech, a town three miles distant. His favourite dog, Nero, is of Norwegian birth, and a highly intelligent animal. He is at liberty to pass his time at either of the houses owned by his master, and he occasionally walks from one to the other. More frequently, however, he goes to the railway station at Llan Bedr, gets into the train, and jumps out at Harlech. Being most probably unable to get out of the carriage, he was on one occasion taken to Salsernau, the station beyond Harlech, when he left the carriage and waited on the platform for the return train to Harlech. If Nero did not make use of 'abstract reasoning,' we may as well give up the use of the term."

A still more remarkable example of canine sagacity on " road and rail " is given by Mrs. A. S. H. Richardson : " The Rev. Mr. Townsend, incumbent of Lucan, was formerly an engineer on the Dundalk line of railway. He had a very intelligent Scotch retriever dog, which used to have a habit of jumping into any carriage in which Mr. Townsend travelled ; but this had been discontinued for a year when the following incident happened. Mr. Townsend and the dog were on the platform at Dundalk station ; Mr. Townsend went to get a ticket for a lady, and during his absence the dog jumped into a carriage, and when the train started, was carried down to Clones (forty miles). There he found himself alone when he jumped out ; he went into the station-master's office and looked about, then into the ticket collector's and searched there, and then ran off to the town of Clones, a mile distant. There he searched the resident engineer's office, and not finding his master, returned to the station and went to the *up* platform. When the up train arrived, he jumped in, but was driven out by the guard. A ballast train then drew up, going on to a branch line which was being constructed to Caran (fifteen miles), but which was not finished yet. The dog travelled on the engine as far as the line went, and then ran the remaining five miles to Caran, where

[1] "Naturalist's Library," vol. x., p. 154.

[2] *Nature*, vol. xx., p. 505.

Mr. Townsend's sister lived. He visited her house, and not finding his master, ran back to the station, and took a return train to Clones, where he slept and was fed by the station-master. At four in the morning he took a goods train down to Dundalk, where he found Mr. Townsend."

In face of what is written above it would be difficult, indeed impossible, to deny to dogs a large share of reason, and the major portion of those attributes and qualities which are so highly esteemed in man himself.

§ 286. The Intelligence of the Elephant.

Everything considered, the elephant is one of the most, if not, indeed, the most sagacious and wisest of all the animals. It has the largest brain of any existing quadrupeds, and the quality of the brain is also very good.

The position assigned to the elephant, as a reasoning animal, is largely based on its power of working with and carrying out the behests of man in war, in the hunting field, in the capture and subjugation of wild elephants, and in the performance of every kind of menial labour. No animal has profited more by its long and intimate association with the lord of creation. The elephant is, out and away, the largest and strongest land animal at present existing on the earth, and his obedience to man is at once a proof of his superior intelligence and of the dictum that all the animals are, and have been, from the earliest times, subject to man's dominion. No animal, not even the dog or the monkey, has shown more wonderful adaptive power. In war and in the hunting field he faces with equanimity and cool courage the most difficult and trying situations. In tiger-hunting he rarely stampedes even when the tiger has sprung upon him and is clinging to him. In capturing and taming wild elephants his services are invaluable. Not only does he assist in driving the wild elephants into the corral or temporary place of confinement, but he enters the corral and actually assists in looping and lassoing the legs of his wild congeners with ropes, and in binding and fixing them to trees. He performs sundry other duties in connection with their further and ultimate subjugation. The working in concert with man in the camp and in the field reveals extraordinary appreciation of cause and effect, and his capacity to interpret man's wishes and plans cannot be surpassed. In some cases he acts as intelligently as man himself. He is especially serviceable as a beast of burden. There is no kind of work he will not perform. He will remove and pile up timber, carry great loads of war material and merchandise, assist in building houses, in clearing jungle, in making roads, in excavating lagoons, &c. Nothing comes amiss, and his great strength enables him to accomplish prodigies in labour.

He is, as indicated, the largest and strongest of animals : he is also the longest lived.

His average age ranges from 100 to 150 years. He is literally the Samson and Methusaleh of the brute creation. Everything about him is great. He occasionally stands more than nine feet high at the shoulders, and is of corresponding weight. While the elephant is the largest living animal known, he is apt to die suddenly from strong emotion, such as terror or great excitement of any kind. He is also apt to die from falls—his great weight causing fatal internal injuries, from which he rarely if ever recovers. The elephant is, as a rule, very gentle and self-denying. In everything he does his own will is subordinated to that of his mahout or driver, who is his acknowledged master. He has been known to wait patiently a whole night in the jungle rather than desert his driver when in an inebriated condition.

He, in a sense, anticipates what is required of him, and needs comparatively little guidance in the performance of the several duties assigned him. This of itself shows a high degree of intelligence.

The elephant possesses to a marked extent many of the best qualities found in animals. He is sagacious, reflective, magnanimous, just, affectionate, sympathetic, and emotional. If he is at times vindictive, it is almost invariably because of injury or injustice done to himself. In such cases he exhibits a remarkably tenacious memory, and pays off an old score, when the time comes, with interest. Many amusing, and at times tragic, stories are told of his retaliations and retributions.

The elephant is an exclusive animal in the matter of caste. If in the wild state a member of the herd misbehaves, and becomes obnoxious from any cause, he is ostracised, and never again admitted into the social circle. Elephants thus banished become the "rogue" elephants of the forest, and as they are disappointed, soured, and morose, and at war with every living thing, they are dangerous in the highest degree to travellers. Elephants in the wild state have their leaders, sentinels, and outposts, and exercise the extreme of caution when they go to drink or browse in new or unknown territories. The Indian elephant is the best known, and the only one employed for domestic purposes in modern times. Its congener, the African elephant, is irritable, intractable, and uncertain in captivity, and, as a consequence, is seldom or never tamed in the present day. Some of the Roman emperors are reported to have subjugated the African species and employed them in pageants, but they can never be implicitly trusted. The Indian elephant makes himself very comfortable in captivity. In the very hot weather, when he is pestered with flies, he provides himself with a palm or other branch, and whisks them off his body. In this operation

he employs his trunk as a hand, and a very pliable and serviceable hand it makes. On other occasions, and for a similar purpose, he covers his body with dust or mud, or thatches it with hay or grass. He also makes a body-scraper by breaking a branch into a convenient length wherewith to remove elephant leeches from his axilla and other depressions and cavities. In this and in other ways he shows his reflective character and great reasoning power.

Some startling episodes are narrated of wild and tame elephants.

Sir E. Tennent[1] states that "Some years ago an elephant which had been wounded by a native, near Hambangtotte, pursued the man into the town, followed him along the street, trampled him to death in the bazaar before a crowd of terrified spectators, and succeeded in making good its retreat to the jungle."

The following is related by the same authority regarding a "rogue" elephant, which charged a party of travellers, who betook themselves to a tree for safety : "The elephant came directly to the tree and attempted to force it down, which he could not. He first coiled his trunk round the stem, and pulled it with all his might, but with no effect. He then applied his head to the tree, and pushed for several minutes, but with no better success. He then trampled with his feet all the projecting roots, moving, as he did so, several times round and round the tree. Lastly, failing in all this, and seeing a pile of timber, which I had lately cut, at a short distance from us, he removed it all (thirty-six pieces), one at a time, to the root of the tree, and piled them up in a regular business-like manner ; then placing his hind feet on this pile, he raised the fore part of his body, and reached out his trunk, but still he could not touch us, as we were too far above him. The Englishman then fired, and the ball took effect somewhere on the elephant's head, but did not kill him. The next shot, however, levelled him to the ground."

Sir E. Tennent also gives an account of the behaviour of a "rogue" elephant which had been captured and which died suddenly of what the hunters call "broken heart." The narrative runs as follows : "Amongst the last of the elephants noosed was the 'rogue.' Though far more savage than the others, he joined in none of their charges and assaults on the fences, as they uniformly drove him off, and would not permit him to enter their circle. When dragged past another of his companions in misfortune, who was lying exhausted on the ground, he flew upon him and attempted to fasten his teeth in his head : this was the only instance of viciousness which occurred during the progress of the corral. When tied up and overpowered, he was at first noisy and violent, but soon lay down peacefully, a sign, according to the hunters, that his death was at hand. Their prognostication was correct ; he continued for about twelve hours to cover himself with dust like the others, and to moisten it with water from his trunk ; but at length he lay exhausted, and died so calmly that, having been moved but a few moments before, his death was only perceived by the myriads of black flies by which his body was almost instantly covered, although not one was visible a moment before."

In 1805, at the siege of Bhurtpore, because of the prevalence of hot dry winds there was a great scarcity of water—practically a water famine. At one of the large wells which still contained water the following scene, according to Mr. Griffiths, occurred : "Two elephant drivers, each with his elephant, the one remarkably large and strong, and the other comparatively small and weak, were at the well together ; the small elephant had been provided by his master with a bucket for the occasion, which he carried on the end of his proboscis, but the larger animal, being destitute of this necessary vessel, either spontaneously, or by the desire of his keeper, seized the bucket, and easily wrested it from his less powerful fellow-servant. The latter was too sensible of his inferiority openly to resent the insult, though it is obvious that he felt it ; but great squabbling and abuse ensued between the keepers. At length the weaker animal, watching the opportunity when the other was standing with his side to the well, retired backwards a few paces in a very quiet and unsuspicious manner, and then, rushing forward with all his might, drove his head against the side of the other, and fairly pushed him into the well. Great trouble was experienced in extricating this elephant from the well—a task which would, indeed, have been impossible but for the intelligence of the animal itself. For when a number of fascines, which had been employed by the army in conducting the siege, were thrown down the well, the elephant showed sagacity enough to arrange them with his trunk so as to construct a continuously rising platform, by which he gradually raised himself to a level with the ground."

Nothing perhaps displays the sagacity and reasoning power of the elephant to greater advantage than the capture and taming of wild elephants by decoys, for the most part female elephants.

Sir E. Tennent says : "Several herds of wild elephants having been drawn into a corral, two tame decoys were ridden into it. One was of prodigious age, having been in the service of the Dutch and English Governments in succession for upwards of a century. The other, called by her keeper 'Siribeddi,' was about fifty years old, and distinguished for gentleness and docility. She was a most accomplished decoy, and evinced the utmost relish for the sport. Having entered the corral noiselessly, carrying a mahout on her shoulders with the headman of the noosers seated behind him, she moved slowly along with a sly composure and an assumed air of easy indifference ;

[1] "Natural History of Ceylon."

sauntering leisurely in the direction of the captives, and halting now and then to pluck a bunch of grass or a few leaves as she passed. As she approached the herd they put themselves in motion to meet her, and the leader, having advanced in front and passed his trunk gently over her head, turned and paced slowly back to his dejected companions. Siribeddi followed with the same listless step, and drew herself up close behind him, thus affording the nooser an opportunity to stoop under her and slip the noose over the hind foot of the wild one. The latter instantly perceived his danger, shook off the rope, and turned to attack the man. He would have suffered for his temerity had not Siribeddi protected him by raising her trunk and driving the assailant into the midst of the herd, when the old man, being slightly wounded, was helped out of the corral, and his son Ranghanie, took his place.

"The herd again collected in a circle, with their heads towards the centre. The largest male was singled out, and two tame ones pushed boldly in, one on either side of him, till the three stood nearly abreast. He made no resistance, but betrayed his uneasiness by shifting restlessly from foot to foot. Ranghanie now crept up, and holding the rope open with both hands (its other extremity being made fast to Siribeddi's collar), and watching the instant when the wild elephant lifted its hind foot, succeeded in passing the noose over its leg, drew it close, and fled to the rear. The two tame elephants instantly fell back, Siribeddi stretched the rope to its full length, and whilst she dragged out the captive, her companion placed himself between her and the herd to prevent any interference.

"In order to tie him to a tree he had to be drawn backwards some twenty or thirty yards, making furious resistance, bellowing in terror, plunging on all sides, and crushing the smaller timber, which bent like reeds beneath his clumsy struggles. Siribeddi drew him stealthily after her, and wound the rope round the proper tree, holding it all the time at its full tension, and stepping cautiously across it when, in order to give it a second turn, it was necessary to pass between the tree and the elephant. With a coil round the stem, however, it was beyond her strength to haul the prisoner close up, which was, nevertheless, necessary in order to make him perfectly fast; but the second tame one, perceiving the difficulty, returned from the herd, confronted the struggling prisoner, pushed him shoulder to shoulder, and head to head, forcing him backwards, whilst at every step Siribeddi hauled in the slackened rope till she brought him fairly up to the foot of the tree, where he was made fast by the cooroowe people. A second noose was then passed over the other hind leg, and secured like the first, both legs being afterwards hobbled together by ropes made from the fibre of the kitool or jaggery palm, which, being more flexible than that of the cocoanut, occasions less formidable ulcerations. The two decoys then ranged themselves, as before, abreast of the prisoner, on either side, thus enabling Ranghanie to stoop under them and noose the two fore feet as he had already done the hind; and these ropes being made fast to the tree in front, the capture was complete, and the tame elephants and keepers withdrew to repeat the operation on another of the herd." . . . "One could almost fancy there was a display of dry humour in the manner in which the decoys thus played with the fears of the wild herd, and made light of their efforts at resistance. When reluctant they shoved them forward, when violent they drove them back; when the wild ones threw themselves down, the tame ones butted them with head and shoulders, and forced them up again. And when it was necessary to keep them down, they knelt upon them, and prevented them from rising, till the ropes were secured.

"At every moment of leisure they fanned themselves with a bunch of leaves, and the graceful ease with which an elephant uses his trunk on such occasions is very striking. It is doubtless owing to the combination of a circular with a horizontal movement in that flexible instrument; but it is impossible to see an elephant fanning himself without being struck by the singular elegance of motion which he displays. The tame ones, too, indulged in the luxury of dusting themselves with sand, by flinging it from their trunks; but it was a curious illustration of their delicate sagacity, that so long as the mahout was on their necks, they confined themselves to flinging the dust along their sides and stomach, as if aware that to throw it over their heads and back would cause annoyance to their riders."

There are good grounds for believing that elephants possess abstract ideas. Thus Mr. H. Jenkins writes: "I think it impossible to doubt that they acquire through their own experience notions of hardness and of weight, and the grounds on which I am led to think this are as follows. A captured elephant, after he has been taught his ordinary duties, say about three months after he is taken, is taught to pick up things from the ground and give them to his mahout sitting on his shoulders. Now for the first few months it is dangerous to require him to pick up anything but soft articles, such as clothes, because the things are often handed up with considerable force. After a time, longer with some elephants than with others, they appear to take in a knowledge of the nature of the things they are required to lift, and the bundle of clothes will be thrown up sharply as before, but heavy things, such as a crowbar or piece of iron chain, will be handed up in a gentle manner, a sharp knife will be picked up by its handle and placed on the elephant's head, so that the mahout can also take it by the handle. I have purposely given elephants things to lift which they could never have seen before, and they were all

handled in such a manner as to convince me that they recognised such qualities as hardness, sharpness, and weight."

The behaviour of the elephant when suffering pain and in bodily trouble is very striking. Dr. Davy when in Ceylon was consulted about an elephant in the Government stud, sick from a deep burrowing sore in the back which required an operation. Dr. Davy, being assured that the animal would be staunch and not misbehave, performed the operation himself. He says : " The elephant was not bound, but was made to kneel down at his keeper's command ; and with an amputating knife, using all my force, I made the incision required through the tough integuments. The elephant did not flinch, but rather inclined towards me when using the knife ; and merely uttered a low and as it were suppressed groan. In short, he behaved as like a human being as possible, as if conscious (as I believe he was) that the operation was for his good, and the pain unavoidable."

Mr. Bingley in his " Animal Biography " (vol. i., p. 155) recounts a similar and even more singular case. He writes : " In the last war in India a young elephant received a violent wound in its head, the pain of which rendered it so frantic and ungovernable that it was found impossible to persuade the animal to have the part dressed. Whenever any one approached it ran off with fury, and would suffer no person to come within several yards of it. The man who had care of it at length hit upon a contrivance for securing it. By a few words and signs he gave the mother of the animal sufficient intelligence of what was wanted ; the sensible creature immediately seized her young one with her trunk, and held it firmly down, though groaning with agony, while the surgeon completely dressed the wound, and she continued to perform this service every day till the animal was perfectly recovered."

The elephant is very fertile in resource. Thus Mr. Jesse observes : " I was one day feeding the poor elephant, Chuny (who was so barbarously put to death at Exeter Change), with potatoes, which he took out of my hand. One of them, a round one, fell on the floor, just out of reach of his proboscis. After several ineffectual attempts to reach it, he at length *blew* the potato against the opposite wall with sufficient force to make it rebound, and he then without difficulty secured it."

The elephant, above all things, is remarkable for his extreme caution, and nothing will tempt him to tread upon anything insecure. He seems fully to realise the danger accruing from his own extraordinary ponderosity.

An old Indian friend told me that on one occasion one of his elephants was crossing a morass fortified with a thick layer of branches to make it safe. The elephant proceeded slowly and cautiously over the quasi bridge of branches, and had nearly reached the other side when some of the branches gave way under him. In an instant he seized his mahout or driver with his trunk and placed him in a prone position across the treacherous path, and stepping on his body saved himself. The elephant saved his own life by sacrificing that of his driver. This was an altogether unusual procedure, as the elephant invariably at once fears and loves his mahout.

The following occurs in Captain Shipp's " Memoirs." Travelling with his force in a mountainous district in India they came upon a steep ascent, and had to construct a staircase of logs for the elephants which was none of the strongest. When the first elephant reached the bottom step and was requested to mount " he looked up, shook his head, and when forced by his driver, roared piteously. There can be no question, in my opinion, but that this sagacious animal was competent instinctively [?] to judge of the practicability of the artificial flight of steps thus constructed ; from the moment some little alteration had been made, he seemed willing to approach. He then commenced his examination and scrutiny by pressing with his trunk the trees that had been thrown across ; and after this he put his fore-leg on with great caution. The next step for him to ascend by was a projecting rock, which he could not remove. Here the same sagacious examination took place, the elephant keeping his flat side close to the side of the trunk, and leaning against it. The next step was against a tree, but this, on the first pressure of his trunk, he did not like. Here the driver made use of the most endearing epithets, such as 'Wonderful,' 'My life,' 'Well done, my dear,' 'My dove,' 'My son,' 'My wife,' but all these endearing appellations, of which elephants are so fond, would not induce him to try again. Force was at length resorted to, and the elephant roared terrifically, but would not move. Something was then altered, the elephant was satisfied, and at last succeeded in mounting to the top of the staircase. On reaching the top his delight was visible in a most eminent degree ; he caressed his keepers, and threw dirt about in a most playful manner."

The elephant, notwithstanding his extreme caution and sober disposition when confronted with danger, has certainly a humorous side to his nature. Every one has heard of the tailor who pricked the elephant's trunk with a needle, and was subsequently drenched with dirty water for his pains.

The following, related by Mr. Charles Young, the actor, of " Chuny," the famous " Exeter Change " elephant, is intensely amusing. Chuny was originally purchased in 1819 by Mr. Harris of the Covent Garden Theatre, London, for the sum of nine hundred guineas, to take part in the pantomime "Harlequin Padmenaba." He was cruelly treated by the management of the theatre through his keeper, a man of colour, who was senselessly compelled to punish him for supposed obstinacy. It was at this juncture that Mr. Charles Young made Chuny's acquaintance. " While

an angry altercation was going on between Young and the man of colour, who was the driver, Captain Hay, of the *Ashel*, who had brought over 'Chuny' in his ship, and had petted him greatly on the voyage, came in and begged to know what was the matter. Before a word of explanation could be given, the much-wronged creature spoke for himself; for, as soon as he perceived the entrance of his patron, he waddled up to him, and, with a look of gentle appeal, caught hold of his hand with his proboscis, plunged it into his bleeding wound, and then thrust it before his eyes. The gesture seemed to say, as plainly as if it had been enforced by speech, 'See how these cruel men treat Chuny. Can *you* approve of it?' The hearts of the hardest present were sensibly touched by what they saw, and among them that of the gentleman who had been so energetic in promoting its harsh treatment."

In the year 1814 Mr. Harris sold Chuny to Mr. Cross, the proprietor of the menagerie at Exeter Change, and it was in this famous wild beasts' show that the amusing incident to which I refer happened. Mr. Young thus relates the facts: "Some years after, when the elephant's theatrical career was run, and he was reduced to play the part of captive in one of the cages of Exeter Change, a thoughtless dandy one day amused himself by teasing him with the repeated offer of lettuces—a vegetable for which he was known to have an antipathy. At last he presented him with an apple, but, at the moment of his taking it, drove a large pin into his trunk, and then sprang out of his reach. The keeper, seeing that the poor creature was getting angry, warned the silly fellow away, lest he should become dangerous. With a contemptuous shrug of the shoulder, he trudged off to the other end of the gallery, and there displayed his cruel ingenuity on other humbler beasts, till, after the absence of half-an-hour, he once more approached one of the cages opposite the elephant's. By this time he had forgotten his pranks with Chuny, but Chuny had not forgotten him, and as he was standing with his back towards him, he thrust his proboscis through the bars of his prison, twitched off the offender's hat, dragged it in to him, tore it to shreds, then threw it into the face of the offending gaby, consummating his revenge with a loud guffaw of exultation."

Poor Chuny came to a miserable and ill-deserved end. He apparently went mad, and an attempt was made to poison him which failed. A detachment of the Guards was then called in, and no fewer than 152 shots were fired before he succumbed. It is now pretty certain that the poor creature was not mad but suffering from an excruciating attack of toothache. His skeleton, a noble one, is preserved in the Royal College of Surgeons of England, and there the offending diseased molar and the traces of the foul play can be distinctly seen.

Nothing would be easier than greatly to increase the number of interesting and instructive anecdotes illustrating the reasoning power of elephants, but no good purpose would be served by so doing. Sufficient has been adduced to show that their mental equipment greatly resembles that of man himself; the difference, such as it is, being less in kind than in degree.

§ 287. The Intelligence of the Monkey Tribe.

It may facilitate our comprehension of this most interesting class of animals if I state as a preliminary, that the order *Primates* has been divided into the sub-orders *Anthropoidea* and *Lemuroidea*—the former including the families of the *Hominidæ*, *Simiadæ*, and *Cebidæ*; the latter the families of the *Lemuridæ*, the *Tarsiidæ*, and *Cheiromyidæ*.

The monkeys have characteristics which separate them more or less from the quadrupeds already described. One of the differences consists in their hind feet being provided with an opposable thumb, and so resembling hands—hence the term quadrumana or four-handed. The modification of the hind feet referred to is necessary to adapt them to their peculiar mode of life, namely, that of living in trees: four hands being more useful in grasping branches than two hands and two feet; feet being more especially adapted for walking on the ground.

"The whole of the apes and the whole of the half-apes agree together, and differ from man, in having the great toe, or (as it is called in anatomy) the hallux, so constructed as to be able to oppose the other toes (much as our thumb can oppose the fingers), instead of being parallel with the other toes, and exclusively adapted for supporting the body on the ground. The prehensile character of the hallux is fully maintained even in those forms which, like the baboons, are terrestrial rather than arboreal in their habits, and are quite quadrupedal in their mode of progression.

"It was this circumstance that led Cuvier to give to that separate order in which he places man alone, the name *Bimana*, while on the order of apes and lemurs he imposed the term *Quadrumana*.

"If we accept, with Professor Owen, as the definition of the word 'foot,' '*an extremity in which the hallux forms the fulcrum in standing or walking*,' then man alone has a pair of feet"[1] (see Figs. 2 and 3 of Plate cxxxv., p. 756).

Another peculiarity is that some of them, at times, assume a semi-erect position. The chief difference consists

[1] "Man and Apes," by St. George Mivart, F.R.S. (*Popular Science Review*, vol. xii., pp. 127, 128.)

in their largely developed nervous system and in the relative quantity and quality of the brain. In this latter respect they more closely resemble man than any of the other animals. At one time it was thought that the brain of the quadrumana differed from that of man in that the cerebrum or upper larger brain did not overlap the lower and lesser brain (the cerebellum) posteriorly. As a matter of fact, no such distinction can be drawn. In both cases the cerebrum or larger brain overlaps the cerebellum or lesser brain, to a slight extent, posteriorly. The difference between the two forms of brain is less in kind than in degree; man possessing, relatively, a much larger and more powerful brain than any member of the quadrumana. Not a few psychologists, and some anatomists and physiologists, claim for man a separate and distinctive brain organisation; they hold that structurally and functionally the brain of man intrinsically differs from the brains of all other animals, and must therefore be placed in a category by itself. Such a distinction, if made, is purely arbitrary, and is not founded on fact. So far as my researches go, they prove that brain substance is fundamentally and intrinsically the same in all animals, but that in the higher animals, and in man, there is proportionately a larger amount of brain, and the brain is more highly differentiated and of better quality. There is a gradation in brain substance and in nerve matter generally, but no clear line of demarcation can be drawn between the brains of the several orders of animals. It cannot be said that the lower animals endowed with brains do not reason and act voluntarily; neither can it be said that reason and mind are reserved for man alone. Still less can it be affirmed that the quadrumana taken separately, of all the animals, share with man his transcendent brain attributes. The nervous system, and the brain, its highest manifestation, is to be regarded as a continuous chain where the links become larger and stronger as we rise in the scale of being, certain links representing types; or better, an ascending stair with platforms at intervals. The platforms correspond with the various groups of animals arranged in an ascending series. There is continuity, structurally and functionally, in the chain and in the stair, and the component elements of each are fundamentally and intrinsically identical. It is not otherwise possible to explain how reason appears low down in the scale of being and culminates in man, and how the vegetative structures and functions which bulk largely in the lower animals still find a place in man, the acknowledged terminal link of the animal series.

A careful microscopic examination of the nervous system of animals and of man reveals the important fact that it is fundamentally one, and consists of a molecular nerve basis in which are imbedded nerve cells with or without connecting nerve fibres; ganglia or nerve centres with nerve cells and connecting nerve fibres, commisural or otherwise; afferent or sensory nerve fibres which, in the higher animals, conduct impressions from without to the spinal cord or the brain; and efferent or motor nerve fibres, which convey impulses from within from the spinal cord or the brain to the muscles. In rudimentary animals, such as the jelly-fish, there are simply nerve cells and nerve fibres; there is neither spinal cord nor brain. In the five-rayed star-fish (Plate lvii., p. 133) there are ganglia or nerve centres to which are added sensory and motor nerves; the former extending between the skin and the nerve ganglia, the latter between the nerve ganglia and the muscles. The ganglia co-ordinate the nerve action, and furnish an apparatus by which sensory impressions can be converted into motor impulses with a certain degree of conscious perception on the part of the animal: the ganglia are, in reality, rudimentary brains, and I have ventured to call them *brainlets*. In the centipede (Plate lvii., p. 133), the first trace of a spinal cord and brain occurs. In this annulated animal the nervous system consists of a longitudinal double chain of commisural nerve fibres, with two sets of ganglia and sensory and motor nerve fibres for each segment of the animal: the two ganglia in the cephalic or head segment approximate and become larger, and unite to form a simple brain. The brain proper, it will be seen, consists of the same elements as occur in the several segments of the body, and is composed of nerve cells, ganglia, and sensory and motor nerves symmetrically arranged.

The longitudinal commisural nerve fibres (which foreshadow a spinal cord) unite the ganglia in the direction of the length of the animal and across the segments, so that all parts of the body are brought under the influence of the brain. In the higher animals, where a spinal cord and brain proper occur, the same arrangement obtains. In the brain, as in the cord, its several parts are connected by commissural nerve fibres, so that while consisting of two symmetrical halves it works as a whole. As the nerve molecules, nerve cells, ganglia, and sensory and motor nerves of each half of the cord preside, so to speak, over the segment of the body to which they naturally belong, so the nerve elements of the brain, which is the predominant partner, preside over the whole body. The brain in the higher animals consists of a molecular nerve blastema richly supplied with blood; a double series of large nerve centres crowded with nerve cells and smaller nerve centres (ganglia); nerve commissures or connecting nerve bands; and a profusion of sensory and motor nerve fibres. The number of the large nerve centres varies according to the degree of differentiation attained by the animal to which they belong. In the fish, proceeding from before backwards, there are two olfactory lobes or bulbs, two cerebral lobes or hemispheres, a cerebellum, and a medulla oblongata (communicating with the spinal cord) arranged in linear series, and not overlapping. In the alligator, the same structures occur, but in greater volume. In the rabbit, the same structures, plus others, are found. The

great nerve centres, each consisting of two symmetrical parts, in the brain of the rabbit, as named from before backwards, are the olfactory bulbs, the cerebral lobes or hemispheres, the corpora striata, the optic thalami, the tubercula quadrigemina, and the medulla oblongata merging into the spinal cord (Plate lvii., Figs. 5 and 6, p. 133).

The peculiarity in the brain of the rabbit consists in an increase in the great nerve centres and a tendency on the part of the cerebral lobes or hemispheres, which constitute the cerebrum or brain proper, to grow upwards, forwards, and backwards, and so to cover in and conceal the other great nerve centres, which now occupy a lower position. In the man-like apes and in man, the upward, forward, and backward expansion of the cerebral lobes becomes so great that they actually do cover in and conceal all the other great nerve centres; the latter occupying a position, in linear series, beneath the cerebral lobes. There is a further important difference. The surfaces of the cerebral lobes in the rabbit become slightly crumpled up, tortuous, and convoluted. The crumpling or folding referred to is most marked in man, and the greater the folding the better the quality of the brain.[1]

As the cerebral lobes constitute the brain proper, and are the recognised organs of thought, this breaking up of their surfaces by furrows or sulci has great significance, as it enormously increases their superficial area and affords space for countless millions of nerve cells and ganglia, and for a bewildering number of commissural or connecting nerve fibres, and of sensory and motor nerves, which extend to every part of the body. The great nerve centres of the human brain, named from before backwards, have been already described, and are briefly as under: the cerebral lobes, the olfactory bulbs, the corpora quadrata, the optic thalami, the corpora quadrigemina, the cerebellum, the medulla oblongata communicating with the spinal cord, and the tuber annulare or ganglion of the medulla oblongata. From the foregoing it will be seen that there is no breach of continuity of the nervous system, from the time it first makes its appearance in the jelly-fish, until it attains its highest development in man. It is a mere question of differentiation and increase. The fundamental elements are the same. As there is no breach of continuity, so there can be no line of demarcation drawn between the reasoning power in the man and the monkey, and between the reasoning power in the monkey and the animals lower down in the scale, where reasoning can be traced. It is, as I have already explained, a question of degree and not of kind; in other words, reasoning, wherever and whenever it occurs, is essentially of the same nature. It is the amount of reasoning power which determines the position of an animal in the scale of being.

As there are varying degrees of reasoning power in animals, so there are varying degrees of consciousness. It is impossible to confine consciousness to man. It certainly exists in the monkeys, and in the elephant, dog, horse, and other animals. It is inconceivable that animals, which certainly reason, are ignorant of their own existence, and of a world outside of themselves. It may be taken for granted that all animals, however low down in the scale of being, which act voluntarily, are conscious within limits. To claim (as some do) that only man can reason and is conscious is to degrade the animals without in any way improving the exalted position occupied by *Homo sapiens*.

The nervous systems and brains of the so-called man apes (and monkeys generally) possess several of the peculiarities of the nervous system and brain of man. Thus, monkeys and men are highly sensitive; they feel bodily and mental pain acutely; they are exceedingly affectionate and sympathetic; they love their offspring and each other, and grieve when any of their fellows are overtaken by calamity, or hurt, or maltreated. They love to be caressed or fondled, and resent neglect and harsh treatment in any form. They have a sense of justice and fair play, and, if cheated and deceived, feelings of suspicion and distrust are engendered in them. They have what may be broadly designated a conscience, and an idea of rewards and punishments as a factor of conduct. They are endowed with memory, and can profit by experience which, in their case, is cumulative and, within limits, transmissible. They can judge between things essentially different, and come to a conclusion as to what had best be done under the circumstances. They are inquisitive and curious, and investigate things for themselves; they have thus within them the elements of improvement and progress. They are emotional and imaginative in a high degree; they are swayed by love and hate; by envy, jealousy, and revenge; by anger and fear; by mirth, laughter, &c. They are prone to imitation, and follow the lead of the stronger will; this is true of offspring and adults alike.

While the quadrumana and man have many things in common, *it by no means follows that man is evolved from the quadrumana.* Man is on an admittedly higher platform, and is separated from the quadrumana by an impassable mental gulf. Man cannot be regarded as a mere animal. He has a mental, moral, and spiritual side, to which due prominence must be given in a philosophical consideration of him as a living entity. It is here that a simian ancestry utterly and absolutely fails, and becomes an impossibility. Man is an original creation—a type by himself—to

[1] It has been found in post-mortem examinations, that the brains of great men are heavier and more richly and deeply convoluted than the brains of ordinary men. The richly convoluted brain is invariably a good working brain. The greater the number and the deeper the convolutions, the better the quality of the brain, as a rule. The most richly and deeply convoluted brain I ever examined (and I have examined several thousands) was that of the late Sir James Young Simpson, Professor of Midwifery in the University of Edinburgh, and he, certainly, was one of the most versatile, gifted, and original men I have ever known.

which all the other members of the animal kingdom lead up. The peculiarities which he shares with the quadrumana he shares, to a greater or less extent, with many other animals lower down in the scale of being. He forms one of the many types which constitute the animal kingdom; these types, as I have explained in previous sections of this work, admitting of variation, within limits, and up to a point. There is no such thing as indefinite variation, and the running or merging of types into each other. This would result ultimately in confusion worse confounded. If there is a tendency to depart from a type, there is also a tendency to return to it, and this explains why domesticated plants and animals, if left to themselves, breed back and return to their originals.

The monkeys have never been turned to any practical account by man. They have never assisted him in discharging any of the numerous duties of civilised life. They cannot be regarded as "hewers of wood and drawers of water" in any sense. The most that can be said is that, as pets, they have afforded him amusement. One great drawback to them as pets is that they are treacherous, tricky, and apt to bite. Their likes and dislikes are often superficial, but they nevertheless possess many human traits which are as admirable as they are remarkable.

Mr. Darwin, in his "Descent of Man" (p. 70), pays a tribute to their affection. He says: "Rengger observed an American monkey (a cebus) carefully driving away the flies which plagued her infant; and Duvancel saw a hylobates washing the faces of her young ones in a stream. So intense is the grief of female monkeys for the loss of their young, that it invariably caused the death of certain kinds kept under confinement by Brehm in North Africa. Orphan monkeys were always adopted and carefully guarded by the other monkeys, both male and female."

Mr. Jobson relates that when an orang-outang was shot by his party from a boat the body was carried away by the survivors. This does not happen with gibbons (*Hylobates agilis*), which are very sympathetic but have no regard for a dead companion.

A writer in *Nature* (vol. ix., p. 243) relates the following: "I keep in my garden a number of gibbon apes (*Hylobates agilis*); they live quite free from all restraint in the trees, merely coming when called to be fed. One of them, a young male, on one occasion fell from a tree and dislocated his wrist; it received the greatest attention from the others, especially from an old female, who, however, was no relation; she used, before eating her own plantains, to take up the first that were offered to her every day, and give them to the cripple, who was living in the eaves of a wooden house; and I have frequently noticed that a cry of fright, pain, or distress from one would bring all the others at once to the complainer, and they would then condole with him and fold him in their arms."

Captain Hugh Crow[1] on one of his voyages had a number of monkeys under observation. He states: "We had several monkeys on board; they were of different species and sizes, and amongst them was a beautiful little creature, the body of which was about ten inches or a foot in length, and about the circumference of a common drinking glass. This interesting little animal, which, when I received it from the Governor of the Island of St. Thomas, diverted me by its innocent gambols, became afflicted by the malady which unfortunately prevailed in the ship. It had always been a favourite with the other monkeys, who seemed to regard it as the last born and pet of the family; and they granted it many indulgences which they seldom conceded to one another. It was very tractable and gentle in its temper, and never took advantage of the partiality shown to it. From the moment it was taken ill their attention and care of it redoubled; and it was truly affecting and interesting to see with what anxiety and tenderness they tended and nursed the little creature. A struggle often ensued among them for priority in those offices of affection, and some would steal one thing and some another, which they would carry to it untasted, however tempting it might be to their own palates. Then they would take it up gently in their fore paws, hug it to their breasts, and cry over it as a fond mother would over her suffering child. The little creature seemed sensible of their assiduities, but it was woefully overpowered by sickness. It would sometimes come to me and look me pitifully in the face, and moan and cry like an infant, as if it besought me to give it relief; and we did everything we could think of to restore it to health; but, in spite of the united attention of its kindred tribes and ourselves, the interesting little creature did not survive long."

Sir James Malcolm gives an interesting account of two common East India monkeys which were greatly attached to each other, and one of which, during a voyage, fell overboard. Its chum became greatly excited, and at once threw the cord which was fastened round its own waist to its drowning companion. The cord was too short to accomplish the object in view. A sailor, however, threw a longer cord, which the drowning monkey promptly seized, and was drawn safely on board.

The following dramatic incident is told by Captain Johnson. He writes: "I was one of a party of Jeekary in the Bahar district; our tents were pitched in a large mango garden, and our horses were picketed in the same garden a little distance off. When we were at dinner a syce came to us, complaining that some of the horses had broken loose in consequence of being frightened by monkeys (*i.e.*, *Macacus rhesus*) on the trees. As soon as dinner

[1] "Narrative of my Life."

was over I went out with my gun to drive them off, and I fired with small shot at one of them, which instantly ran down to the lowest branch of the tree, as if he were going to fly at me, stopped suddenly, and coolly put his paw to the part wounded, covered with blood, and held it out for me to see. I was so much affected at the time that it left an impression never to be effaced, and I have never since fired a gun at any of the tribe."

That monkeys can assume an intensely human expression was painfully illustrated in my own experience while I was engaged at the Hunterian Museum of the Royal College of Surgeons of England (London). I wished to obtain accurate information regarding the movements of the several compartments (auricles and ventricles) of the heart in the higher mammals, and procured a living monkey to settle some disputed points. With the aid of an assistant I put the body of the monkey in a bag to prevent it scratching, and administered chloroform. It somehow seemed to divine my purpose, and while I was administering the anæsthetic it gave me a look of saddened submission, mingled with apprehension, which was very touching. Nothing would induce me to experiment with another monkey. It behaved as a child would when forced to take chloroform against its will.

I remember on one occasion at the Zoological Gardens, London, being particularly struck with the semi-human conduct of a young female chimpanzee. Her keeper, to whom she was greatly attached, gave her a little tin case containing a mixture of rice and gravy, of which she was very fond. She took the can with her two hands and holding it to her mouth slowly sipped the contents. As some of the rice remained in the bottom of the can she scooped it out with the fingers of her right hand and finally ate it. She wanted to play with the empty can, but the keeper wished it returned to him, and insisted on its being given up. She suddenly lost her temper, frowned, and sulked —threw the empty tin at him, and then with a vigorous bound leaped up to her quasi-bedroom and covered herself entirely with her blanket. Her conduct exactly resembled that of a petted, spoiled child.

Monkeys have a comic as well as a tragic side to their character. Mr. Romanes, in the *Quarterly Journal of Science*, mentions a case where a female orang-outang used to place her empty feeding tin on her head in an inverted position, which greatly amused her visitors, and apparently much gratified herself.

Dr. Savage [1] affirms that chimpanzees assemble at times for play pure and simple, and that, on such occasions, they drum with pieces of stick on sonorous pieces of wood.

That monkeys enjoy play and practical jokes is proved by the antics in which they indulge in zoological collections and menageries. They are continually doing something which borders on the ridiculous, and their life in captivity is a strange mixture of playful, good-natured sallies, and of sudden savage attacks on each other. The one moment they are friends and the next they are squabbling, and, it may be, fighting seriously. The monkey-house in all collections is a favourite resort, and every one who studies monkeys is struck with their numerous tricks, some of them exceedingly human in a way. I remember on one occasion seeing a fashionably dressed lady teasing a large baboon with a beautiful silk parasol. The baboon watched his opportunity, and suddenly seized the offending article. He withdrew with his prize to the corner of his cage, and there, to the intense amusement of the onlookers, deliberately tore it to shreds. The lady, I need scarcely add, looked very foolish, and was much mortified.

Sir Andrew Smith was an eyewitness of the following, as narrated by Mr. Darwin: "At the Cape of Good Hope, an officer had often plagued a certain baboon, and the animal, seeing him approaching one Sunday for parade, poured water into a hole and hastily made some thick mud, which he skilfully dashed over the officer as he passed by, to the amusement of many bystanders. For long afterwards the baboon rejoiced and triumphed whenever he saw his victim."

Monkeys are intensely curious. If a looking-glass be given to them they contemplate themselves for a moment, and look quickly behind the glass to see, not themselves, but what they believe to be another monkey. They soon discover the imposture, and are, at times, very angry at having been taken in. Mr. Darwin relates how on one occasion he put a small snake in an open paper bag into the monkey-house at the Zoological Gardens. The monkeys have a perfect horror of snakes, yet every one of them had a quick stolen peep into the bag.

Monkeys are very discriminating. Rengger states that if they are once cut with edge tools, they never touch them again, or handle them very cautiously. If sugar be given to them in a paper bag with a live wasp enclosed and they get stung, they always afterwards put the bag to their ears before opening it. Similarly, if eggs are given to them and they smash them and lose the contents, they chip the ends of the eggs on some hard substance and peel off the egg-shell with their fingers.

Monkeys at times display great ingenuity. Mr. Belt relates how a tamed cebus, when its chain got entangled, unwound it with great adroitness; it also used a swing in bringing things which it desired to possess nearer to it; it also picked the pockets of those who petted it. The illustrious Cuvier had an orang-outang which was wont to draw a chair from one end of the room to the other, so as to stand upon it and reach a latch it desired to open.

[1] *Boston Journal of Natural History*, p. 324.

Rengger speaks of a monkey which employed a stick to prise open the lid of a chest, thus indicating a knowledge of the lever. Mr. Haden gives the following, illustrating intuitive mechanical knowledge. He had a large monkey who wished to get at the branch of a tree which hung over the top of his cage. He could get at it by climbing on the top of the door of his cage, but as the door was hung to close when opened, his efforts were frustrated. He, however, was equal to the occasion. He opened the door and threw over the top of it a thick blanket, which prevented the door from shutting, and so attained his object.

Lieutenant Shipp in his "Memoirs" states that the Cape baboons collect and throw stones and other missiles when attacked from below, and when they are in a position to do so.

Monkeys, moreover, as Dampier and Wafer point out, have been known to use stones as hammers in breaking open oyster-shells.

The performances of monkeys are largely imitations. They share the faculty of imitation with many of the lower animals, and also with children, savages, and semi-civilised people. Every one knows the story of the pedlar and the red nightcaps. The pedlar, exhausted with his burden and the heat, fell asleep in a forest where monkeys abounded, and, before doing so, opened his pack and put on one of his own red nightcaps. No sooner was he in the arms of Morpheus than the monkeys, which had been watching him from high neighbouring trees, descended, and each donned a red nightcap, with which it promptly decamped aloft. When the pedlar awoke he was horrified to find most of his nightcaps gone. In rage and desperation he threw his own nightcap on the ground; unexpectedly, and to his intense delight, all the monkeys followed suit, and he recovered in the easiest way possible, and quite unintentionally, his lost and much valued property.

The faculty of imitation may be over-rated, but some monkeys can do more than imitate—they can investigate. A brown capuchin (*Cebus fatuellus*) learned how to screw and unscrew the handle of a brush. "At first he put the wrong end of the handle into the hole, but turned it round and round the *right way for screwing*. Finding that it did not hold, he turned the other end of the handle and carefully stuck it into the hole, and began again to turn it the right way. It was of course a very difficult feat for him to perform, for he required both his hands to hold the handle in the proper position and to turn it between his hands in order to screw it in. He held the brush with his hind hand, but even so it was very difficult for him to get the first turn of the screw to fit into the thread. He worked at it, however, with the most unwearying perseverance until he got the first turn of the screw to catch, and he then quickly turned it round and round until it was screwed up to the end. The most remarkable thing was that, however often he was disappointed in the beginning, he never was induced to try to turn the handle the wrong way; he always screwed it from right to left. As soon as he had accomplished his self-imposed task, he unscrewed it again, and then screwed it in the second time rather more easily than the first, and so on many times. When he had become by practice tolerably perfect in screwing and unscrewing, he gave it up and took to some other amusement. One remarkable thing is that he should take so much trouble to do that which was no material benefit to himself. The desire to accomplish a chosen task seemed a sufficient inducement to lead him to take any amount of trouble. This was quite a human desire, such as is not shown, I believe, by any other animal. It was not the love of praise, as he never noticed people watching his operations; it was simply the desire to achieve an object for the sake of achieving it.

"The same monkey learned to open and shut folding shutters with ease, and this seemed to be an amusement to him. He also unscrewed all the knobs of a fender. The bell-handle beside a mantelpiece he likewise took to bits, which involved the unscrewing of three screws."

From the foregoing it will be seen that the brown capuchin monkey (*Cebus fatuellus*) is an unusually intelligent animal. He is, in some respects, one of the most intelligent of the monkey tribe. Like other tame animals, he no doubt has profited largely from his association with man, and in coming in contact with the articles and appliances employed by man in his home. In the wild state his intelligence would have been rated considerably lower, and for two reasons: (*a*) the articles and appliances which elicited his intelligence in captivity would have been wanting, and (*b*) his great power of imitation would not have been brought into play to anything like the same extent. His contact with human beings naturally gave a human turn to everything he did. This is true of his general behaviour, such as rolling himself in blankets at night, of throwing things, of his manner of drawing articles towards himself, of his employment of a cane in beating people, of his breaking his nuts with a hammer, of his prizing open the lid of a box with a lever, of his mode of breaking a stick, of his screwing and unscrewing the handle of a brush, of his shaking hands, of his lighting tapers at the fire and watching them burning, of his strewing warm ashes on his head, &c.

Of course it has to be admitted that in this particular case there was the latent intelligence which was evoked by the human surroundings; a remark which holds true of all the domestic animals. Monkeys are only occasionally tamed and domesticated; their connection with man has consequently been non-continuous, and of shorter duration

than that of the domestic animals proper. All this is in favour of the quick wit and great adaptive power of monkeys as a whole. Still, when everything has been said that can be said in favour of their intelligence, it must be admitted that there is a great intellectual gulf between the monkey and the man which no amount of ingenuity can satisfactorily bridge over. The gulf in question affords strong presumptive proof that man is not descended from a simian ancestor. It must also be admitted that the intellect of the monkey, in quantity and quality, is very much nearer that of the domestic animals, especially the dog and the elephant, than that of man.

The gulf which, it appears to me, cannot be bridged over either from the embryological or comparative anatomy side, becomes very apparent when the monkeys, as a whole, are contrasted with the several races of mankind. The monkeys cannot build houses, they cannot cultivate the soil, they cannot raise fire, they cannot make or employ tools, they cannot speak, they cannot read or write, they cannot record events, they cannot hand down their individual experiences to their offspring, unless in a very limited sense, they cannot change the appearance of the earth's surface by cutting down timber and draining land, they cannot alter the earth's climate, they cannot construct railway lines, divert waterways, excavate canals, and tunnel mountains, they cannot construct locomotives and steam-boats, they cannot lay telegraphic wires over land and sea, they cannot employ telephones, phonographs, and wireless telegraphy, they cannot construct microscopes and telescopes, they cannot devise and employ fire-arms, they are ignorant of the great engines of war, their knowledge of nature and the resources of nature is very partial and limited as regards amount, they are unacquainted with science, they cannot philosophise, they can scarcely be said to indulge in abstract thought, they cannot moralise.

The highest monkeys cannot compare with the highest men. Those who hold that man is descended from the monkey endeavour to bolster up *the evolution theory* by saying that there is a greater intellectual difference between the lowest and highest monkeys, than there is between the highest monkey and the lowest man; also that the lowest man differs as much intellectually from the highest man, as the lowest monkey differs from the highest monkey.

I would, however, point out that unless the theory of evolution be accepted in its totality, the only just comparison must be between the lowest monkeys and the lowest men, and between the highest monkeys and the highest men. The argument, however ingenious, is not otherwise a solid one. The only evolution which I can recognise is that connected with growth, differentiation, and development, especially fœtal development, but even in this form of evolution I have to observe that nothing can be evolved which is not originally involved, and that design, and not chance, determines the nature and the amount of development.

The monkeys which most closely resemble man are the orang-outang (*Satyrus orang*), chimpanzee (*Anthropithecus niger*), and gorilla (*Gorilla gina*). The orangs represent the Asiatic anthropoid apes; the chimpanzees and gorillas the African anthropoid apes. They are, for the most part, large, powerful animals, the giant gorilla having a body 6 feet 8 inches long, the span of the outstretched arms measuring no less than 6 feet 9 inches. The anthropoid apes occasionally affect the semi-erect position. As a rule, they walk on all fours like other quadrupeds. They are characterised by very long arms and comparatively short legs; the feet being really hands adapted for grasping branches and not for walking.

It is a mistake to attach too much importance to the so-called semi-erect position in the anthropoidal apes. This is mainly due to their excessively long, powerful arms, which, as explained, when the animals are standing or walking, raise the anterior part of the body much higher than the posterior part; the latter being provided with short, weak limbs. The long, powerful arms and hands, and the short, weak legs and hand-like feet do not necessarily establish a relationship between the anthropoid apes and man. The argument cuts the other way. Man is erect, not because he has very powerful arms and short, feeble legs, but because he has rather short arms, and long, very powerful legs, which being connected to his pelvis and trunk by strong muscles necessitate his assuming and maintaining the erect position. His feet, moreover, are primarily formed for walking.

According to Professor Haeckel,[1] "The existing anthropoid apes are only a small remnant of a large family of eastern apes (or *Catarrhini*), from which man was [said to be ?] evolved about the end of the tertiary period. They fall into two geographical groups—the Asiatic and the African anthropoids. In each group we can distinguish two genera. The oldest of these four genera is the gibbon (*Hylobates*); there are from eight to twelve species of it in the East Indies. . . . The second, larger and stronger, genus of Asiatic anthropoid ape is the orang (*Satyrus*); he is now found only in the islands of Borneo and Sumatra. Selenka, who has lately published a very thorough 'Study of the Development and Cranial Structure of the Anthropoid Apes' (1899), distinguishes ten races of the orang, which may, however, also be regarded as 'local varieties or species.' . . . Several species have lately been distinguished in the two genera of the black African anthropoid apes (chimpanzee and gorilla). In the genus *Anthropithecus* (or *Anthropopithecus*, formerly *Troglodytes*) the bald-headed chimpanzee, *A. calvus*, and the gorilla-like *A. mafuca* differ very strikingly from the ordinary *Anthropithecus niger*, not only in the size and proportion of many parts of the body,

[1] "The Evolution of Man." Watts & Co., London, 1895.

but also in the peculiar shape of the head, especially the ears and lips, and in the hair and colour. . . . Of the largest and most famous of all the anthropoid apes, the gorilla, Paschen has lately discovered a giant form in the interior of the Cameroons, which seems to differ from the ordinary species (*Gorilla gina*), not only by its unusual size and strength, but also by a special formation of the skull. . . . The whole structure of this huge anthropoid ape is not merely very similar to that of man, but it is substantially the same."

The late Mr. St. George Mivart, F.R.S.,[1] does not identify any of the apes with man. He says: "It is manifest that man, the apes, and half-apes cannot be arranged in a single ascending series, of which man is the term and culmination.

"We may, indeed, by selecting one organ, or one set of parts, and confining our attention to it, arrange the different forms in a more or less simple manner. But, if all the organs be taken into account, the cross relations and interdependencies become in the highest degree complex and difficult to unravel. . . . The human structural characters are shared by so many and such diverse forms, that it is impossible to arrange even groups of genera in a single ascending series from the aye-aye to man (to say nothing of so arranging the several single genera), if all the structural resemblances are taken into account. . . . The liver of the gibbons proclaims them almost human: that of the gorilla declares him comparatively brutal. . . . The ear lobule of the gorilla makes him our cousin; but his tongue is eloquent in his own dispraise. . . . The slender lori, from amidst the half-apes, can put in many a claim to be our shadow refracted, as it were, through a lemurine prism. . . . The lower American apes meet us with what seems 'the front of Jove himself,' compared with the gigantic but low-browed denizens of tropical Western Africa. . . . In fact, in the words of the illustrious Dutch naturalists, Messrs. Schroeder, Van der Kolk, and Vrolik,[2] the lines of affinity existing between different primates construct rather a network than a ladder. It is indeed a tangled web, the meshes of which no naturalist has as yet unravelled by the aid of [so-called] natural selection. Nay, more, these complex affinities form such a net for the use of the teleological retiarius as it will be difficult for his Lucretian antagonist to evade, even with the countless turns and doublings of Darwinian evolutions. . . . However near to apes may be the body of man, whatever the kind or number of resemblances between them, it should always be borne in mind that it is to no one kind of ape that man has any special or exclusive affinities—that the resemblances between him and lower forms are shared in not very unequal proportions by different species; and be the preponderance of resemblance in which species it may, whether in the chimpanzee, the siamang, or the orang, there can be no question that at least such preponderance of resemblance is *not* presented by the much vaunted gorilla, which is no less a brute and no more a man than is the humblest member of the family to which it belongs. . . . We must entirely dismiss, then, the conception that mere anatomy by itself can have any decisive bearing on the question as to man's nature and being as a whole. To solve this question, recourse must be had to other studies: that is to say, to philosophy, and especially to that branch of it which occupies itself with mental phenomena—psychology. . . . The difference between the brain of the orang and that of man, as far as yet ascertained, is a difference of absolute mass. It is a mere difference of degree and not of kind. Yet the difference between the mind of man and the psychical faculties of the orang is a difference of kind and not one of mere degree. . . . With how much force, then, does not the comparative anatomy of the present day re-echo the truth long ago proclaimed by Buffon,[3] that material structure and physical forces can never alone account for the presence of mind. . . . Professor Huxley has sought to invalidate such inferences, first by asserting, what is of course perfectly true, that intellectual power (as we daily experience it) depends not on the development of the brain alone, but also on that of 'the organs of the senses and of the motor apparatuses.' . . . Now it is not the chimpanzee, certainly not the gorilla, nor yet the gibbons, which most resemble man as regards his brain. In this respect the orang stands highest in rank. In the first place, the height of the orang's cerebrum in front is greater in proportion than in either the chimpanzee or the gorilla; while the brain of the last-named animal falls below that of the chimpanzee, in that it is relatively longer and more depressed, as compared with man's brain. . . . The actual and absolute mass of the brain is, however, slightly greater in the chimpanzee than in the orang, as is the relative vertical extent of the middle part of the cerebrum, although, as before said, the frontal portion is higher in the orang. When we turn to the gorilla we find, from M. Gratiolet, that this much vaunted and belauded ape is not only inferior to the orang in cerebral development, but even to his small African congener—the chimpanzee. . . . Altogether, M. Gratiolet tells us, its brain-characters make of the gorilla—in spite of its size and strength—the lowest and most degraded of all the latisternal apes. . . . There can be no question, then, but that in this most important organ, the orang is man's nearest ally, while the gorilla is quite remarkably inferior."

What especially strikes one in the gorilla is the low, narrow forehead and the great want of brain capacity. The orangs and chimpanzees have, on the whole, better heads. There is admittedly great similarity between the

[1] "Man and Apes." (*Popular Science Review*, vol. xii., p. 256 *et seq.*)
[2] *Natural History Review*, vol. ii., p. 117.
[3] *Hist. Nat.*, t. xiv., p. 61, 1766.

anthropoid apes and man in bodily configuration. The quadrumana and man are mainly separated by the former having much smaller brains and much less brain power than the latter, and by the fact that the quadrumana are adapted for arboreal life and not for walking. There are other and minor differences, such as the small space between the eyes, the small, flat nose, enormous mouth and teeth, and the hairy exterior.

As Professor Haeckel is, on the whole, the most advanced of modern evolutionists, it may be well if I give in this place an abbreviated account of his theory of the "Evolution of Man."[1] He says: "The *Primates* are now generally divided into three orders—the half-apes (*Prosimiæ*), apes (*Simiæ*), and man (*Anthropi*). The half-apes are the stem group, descending from the older *Mallotheria* of the Cretaceous period. From them the apes were evolved in the Tertiary period, and man was formed from these towards its close [?]. . . . The numerous fossil remains of half-apes and apes that have been recently found in the Tertiary deposits justify us in thinking that man's ancestors were represented by several different species during this long period. We may divide the earlier of them into two groups of prosimiæ: the *Lemuravidæ* of the earlier Eocene and the *Lemurogona* of the later Tertiary. Some of these were almost as big as men, such as the diluvial lemurogonon *Megaladapis* of Madagascar. . . . We can trace a gradual and uninterrupted advance in the organisation of the ape up to the purely human frame, and, after impartial examination of the 'ape-problem' that has been discussed of late years with such passionate interest, we come infallibly to the important conclusion, first formulated by Huxley in 1863: 'Whatever systems of organs we take, the comparison of their modifications in the series of apes leads to the same result: that the anatomic differences that separate man from the gorilla and chimpanzee are not as great as those that separate the gorilla from the lower apes.' . . . The order of the true apes (*Simiæ* or *Pitheca*)—excluding the lemurs—has long been divided into two principal groups, which also differ in their geographical distribution. One group (*Hesperopitheca*, or western apes) live in America. The other group, to which man belongs, are the *Eopitheca* or eastern apes; they are found in Asia and Africa, and formerly in Europe. . . . The apes of the Old World, or all the living or fossil apes of Asia, Africa, and Europe, have the same dentition as man. On the other hand, all the American apes have an additional premolar in each half of the jaw. They have six molars above and below on each side, or thirty-six teeth altogether. . . . Man has just the same characters, the same form of dentition, auditory passage, and nose, as all the catarrhines; in this he radically differs from the platyrrhines. We are thus forced to assign him a position among the eastern apes in the order of primates, or at least place him alongside of them. But it follows phylogenetically [?] that man is a direct blood relative of the apes of the Old World, and can be traced to a common stem-form, together with all the catarrhines. In his whole organisation and in his origin man is a true catarrhine; he originated in the Old World from an unknown, extinct group of the eastern apes. The apes of the New World, or the platyrrhines, form a divergent branch of our genealogical tree, and this is only distantly related at its root to the human race. . . . Naturally, our catarrhine ancestors must have passed through a long series of different forms before the human type was produced. The chief advances that effected this 'creation of man,' or his differentiation from the nearest related catarrhines, were: the adoption of the erect position, and the consequent greater differentiation of the fore and hind limbs, the evolution of articulate speech and its organ, the larynx, and the further development of the brain and its function, the soul.[2] . . . The gorilla comes next to man in the structure of the hand and foot, the chimpanzee in the chief features of the skull, the orang in brain development, and the gibbon in the formation of the chest. . . . Although man is directly connected with this anthropoid family and originates from it, we may assign an important intermediate form between the *Prothylobates* and him, namely, the ape-men (*Pithecanthropi*). I gave this name in the 'History of Creation' to the 'speechless primitive men' (*Alali*), which were men in the ordinary sense as far as the general structure is concerned (especially in the differentiation of the limbs), but lacked one of the chief human characteristics, articulate speech and the higher intelligence that goes with it, and so had a less developed brain. . . . As the pithecanthropus walked erect, and his brain (judging from the capacity of his skull) was midway between the lowest man and the anthropoid apes, we must assume that the next great step in the advance from the pithecanthropus to man was the further development of human speech and reason.

"Comparative philology has recently shown that human speech is polyphyletic in origin, that we must distinguish several (probably many) different primitive tongues that were developed independently. The evolution of language also teaches us (both from its ontogeny in the child and its phylogeny in the race) that human speech proper was only gradually developed after the rest of the body had attained its characteristic form. It is probable that language was not evolved until after the dispersal of the various species and races of men [?], and this probably took

[1] "Evolution of Man," vol. ii., p. 617 *et seq.* Watts & Co., London, 1905.

[2] It will be noted that whilst Haeckel refers man's ancestry to the nearest catarrhines he gives no hint as to how man acquired his superior structure and mental endowment. The greater differentiation of the limbs, the erect position, the production of the larynx and articulate speech, and the greater development of the brain and soul, cannot be regarded as accidental. They are the outcome of design, and separate man, as a type, from the apes and all the animals beneath the apes.

place at the commencement of the Quaternary or Diluvial period. The speechless ape-men or alali certainly existed towards the end of the Tertiary period, during the Pliocene, possibly even the Miocene, period.

"The third, and last, stage of our animal ancestry is the true or speaking man (*Homo*), who was gradually evolved from the preceding stage by the advance of animal language into articulate speech. As to the time and place of this real 'creation of man' we can only express tentative opinions. It was probably during the Diluvial period in the hotter zone of the Old World, either on the mainland in tropical Africa or Asia, or on an earlier continent (Lemuria—now sunk below the waves of the Indian Ocean), which stretched from East Africa (Madagascar, Abyssinia) to East Asia (Sunda Islands, Further India)."

It will be seen that Professor Haeckel makes heroic and persistent efforts to trace man back to the monkeys. Indeed, he asserts man's ancestry with a vigour and confidence not at all justified by the facts. He has himself created a speechless man (*Pithecanthropus*) as a connecting link "midway between the lowest men and the anthropoid apes." This speechless man—originally a figment of his imagination—he asserts was brilliantly confirmed, twenty-four years after he prophesied his existence, by Eugene Dubois, who in 1892 found in Trinil, in the residency of Madian at Java, in Pliocene deposits, certain remains of a large and very manlike ape (roof of the skull, femur, and teeth), which he described "as an erect ape-man" and a survivor of a "stem-form of man." The paucity of the remains found by Dubois, namely, the roof of the skull, femur, and teeth, does not at all justify the weighty conclusions drawn from them. They certainly do not prove that the ape found had attained to the erect position, and was a man, minus the voice.

It may be well in this connection to refer to two other finds, namely, the fragmentary skulls discovered in the cave of Engis in the valley of the Meuse (Belgium), and that of the Neanderthal, near Düsseldorf. According to Sir Charles Lyell the Engis skull belonged to a contemporary of the mammoth (*Elephas primigenius*) and of the woolly rhinoceros (*Rhinoceros tichorhinus*), with the bones of which, and with those of the horse, hyena, and bear, it was mixed up.

The Neanderthal skull was also believed to be of great antiquity, although no definite date could be assigned.

The Engis skull was originally discovered by Professor Schmerling, and was described by him in 1833.[1] He regarded it as the skull of an old person. The facial bones and base of the skull were wanting, only the top of the cranium and a fragment of the right temporal bone being preserved. He was struck with the low, narrow, and elongated form of the forehead, and regarded the cranium as more of an Ethiopian than European type. He believed the cranium belonged to a person of limited intellectual faculties—to a man of a low degree of civilisation.

Schmerling obtained from the cave of Engihoul, opposite the Engis cave, fragments of three other human skeletons, including portions of two parietal bones and many bones of the extremities. The Engihoul cave also contained a pointed bone implement, evidently of human origin; worked flints being found by him in all the Belgian caves, which yielded an abundance of fossil bones. The human remains are associated with flint implements, which indicates a certain degree of civilisation.

M. Geoffroy St. Hilaire inspected Schmerling's collection of fossil bones at Liège, and makes the following remarks concerning the crania: "With respect to their special forms, compared with those of the varieties of recent human crania, few *certain* conclusions can be put forward; for much greater differences exist between the different specimens of well-characterised varieties, than between the fossil cranium of Liège and that of one of those varieties selected as a term of comparison."[2]

Professor Huxley differs from Schmerling in his estimate of the Engis skull. He says: "The roof of the skull was very regularly and elegantly arched in the transverse direction; the forehead cannot be called narrow in relation to the rest of the skull, nor can it be called a retreating forehead: the supraciliary prominences or brow-ridges are well, but not excessively developed, and are separated by a median depression. Their principal elevation is disposed so obliquely that I judge them to be due to large frontal sinuses."[3]

It will be seen that the Engis skull cannot be regarded as a connecting link between man and the apes.

Similar remarks are to be made of the Neanderthal skull originally described by Dr. Schaaffhausen.[4] He remarks: "In the early part of the year 1857, a human skeleton was discovered in a limestone cave in the Neanderthal, near Hochdal, between Düsseldorf and Elberfeld. Of this, however, I was unable to procure more than a plaster cast of the cranium, taken at Elberfeld, from which I drew up an account of its remarkable conformation, which was, in the first instance, read on the 4th of February, 1857, at the meeting of the Lower Rhine Medical and Natural History Society, at Bonn."

Schaaffhausen had subsequently an opportunity of examining the skull itself and the other bones found with

[1] "Recherches sur les Ossemens fossiles découverts dans les cavernes de la province de Liège."
[2] *Comptes Rendus*, Academy of Sciences, Paris, for July 2nd, 1838.
[3] "Man's Place in Nature and other Anthropological Essays." London, 1901, pp. 167, 168.
[4] "On the Crania of the most Ancient Races of Man." (From Müller's "Archiv.," 1858, p. 453.)

it. The following are his conclusions: 1st. That the extraordinary form of the skull was due to a natural conformation hitherto not known to exist, even in the most barbarous races. 2nd. That these remarkable human remains belonged to a period antecedent to the time of the Celts and Germans, and were in all probability derived from one of the wild races of North-western Europe, spoken of by Latin writers, which were encountered as autochthones by the German immigrants. And 3rdly. That it was beyond doubt that these human relics were traceable to a period at which the latest animals of the diluvium still existed; but that no proof of this assumption, nor consequently of their so-termed *fossil* condition, was afforded by the circumstances under which the bones were discovered.

"The cranium is of unusual size, and of a long, elliptical form. A most remarkable peculiarity is at once obvious in the extraordinary development of the frontal sinuses, owing to which the superciliary ridges, which coalesce completely in the middle, are rendered so prominent, that the frontal bone exhibits a considerable hollow or depression above, or rather behind them, whilst a deep depression is also formed in the situation of the root of the nose. The forehead is narrow and low, though the middle and hinder portions of the cranial arch are well developed."

Professor Huxley compared the Neanderthal skull to that of the aboriginal Australian.

"Besides the cranium, the following bones have been secured:—

"1. Both thigh bones, perfect. These, like the skull, and all the other bones, are characterised by unusual thickness, and the great development of all the elevations and depressions for the attachment of muscles.

"2. A perfect right radius of corresponding dimensions, and the upper third of a right ulna corresponding to the humerus and radius.

"3. A left humerus, of which the upper third is wanting, and which is so much slenderer than the right as apparently to belong to a distinct individual; a left ulna, which, though complete, is pathologically deformed, the coronoid process being so much enlarged by bony growth, that flexure of the elbow beyond a right angle must have been impossible; the anterior fossa of the humerus for the reception of the coronoid process being also filled up with a similar bony growth. When the left ulna is compared with the right radius, it might at first sight be concluded that the bones respectively belonged to different individuals, the ulna being more than half an inch too short for articulation with a corresponding radius. But it is clear that this shortening, as well as the attenuation of the left humerus, are both consequent upon the diseased condition above described.

"4. A left ilium, almost perfect, and belonging to the femur; a fragment of the right scapula; the anterior extremity of a rib of the right side; and the same part of a rib of the left side, &c."

It is plain to me that the thickened cranium and bones of the Neanderthal skeleton described by Schaaffhausen were diseased, a not uncommon thing in modern life. I have in my own collection, at St. Andrews University, numerous examples of such bones: one cranium considerably more than a quarter of an inch thick, and several long bones, flat bones, ribs, &c., quite twice the usual size.

It would be exceedingly risky to found an argument of pithecoid peculiarities and great strength on the appearances presented by the Neanderthal skeleton. That the bones were those of a low, abnormal, diseased individual there can, I think, be no doubt whatever.

Schaaffhausen concludes his description as follows: "Sufficient grounds exist for the assumption that man co-existed with the animals found in the *diluvium;* and many a barbarous race may, before all historical time, have disappeared, together with the animals of the ancient world, whilst the races whose organisation is improved have continued the genus. The bones which form the subject of this paper present characters which, although not decisive as regards a geological epoch, are, nevertheless, such as indicate a very high antiquity. . . . Nor should we be justified in regarding the cranial conformation as perhaps representing the most savage primitive type of the human race, since crania exist among living savages, which, though not exhibiting such a remarkable conformation of the forehead, which gives the skull somewhat the aspect of that of the large apes, still in other respects, as for instance in the greater depth of the temporal fossæ, the crest-like, prominent temporal ridges, and a generally less capacious cranial cavity, exhibit an equally low stage of development."

The outstanding features in the Neanderthal skull are the small, flat forehead, and the abnormally developed supra-orbital ridges. Disease and arrest of development would largely account for both. In this connection it is necessary to point out that, in modern civilised life, diseased, thickened bones are of frequent occurrence, and every one acquainted with mental diseases knows very well that certain imbeciles and idiots have literally no foreheads or brain capacity. I have seen many such, and I have in my University collection at St. Andrews casts of idiot crania which reveal a lower type of head than even the Neanderthal one; nor must it be forgotten that the heads of Aztecs (see Fig. 225, p. 783) living at the present day are on quite as low a level as the Neanderthal head as regards brain capacity. I examined very carefully, so recently as December 1904, a male and female Aztec, each

sixty years of age, on show at Marseilles, France. They had then been on show thirty-nine years, and were in good physical health. They had travelled in Europe, America, and other countries, and have doubtless been seen by most of the savants in the civilised world. Their front heads are so low and so receding that they appear to be sliced away. These are cases of arrested development. The Aztecs, who are natives of Mexico, are not idiots, but their intellect is the feeblest possible.

In addition to the Engis and Neanderthal crania and bones referred to, two ancient skeletons have been found at the mouth of a cave in the commune of Spy, in the Belgian province of Namur. These have been described by Messrs. Fraipont and Lohest,[1] and it is claimed that they resemble the Neanderthal bones. The authors in question, speaking of one of the skeletons, say: "The distance which separates the man of Spy from the modern anthropoid ape is undoubtedly enormous; between the man of Spy and the *Dryopithecus* it is a little less. But we must be permitted to point out that if the man of the later Quaternary age is the stock whence existing races have sprung, he has travelled a very great way. From the data now obtained, it is permissible to believe that we shall be able to pursue the ancestral type of men and the anthropoid apes still further, perhaps as far as the Eocene and even beyond."

From what is stated above, we are, it appears to me, forced to conclude that none of the so-called fossil skulls can be regarded as connecting links between man and the ape; nor can Professor Haeckel's speechless man-ape be permitted to figure in that capacity. While there is an admittedly enormous mental gap between man and the apes, there are still great structural gaps which no amount of ingenious special pleading can bridge over. Man physically, mentally, and morally has obviously no ancestor but himself. He is an original type, and, as such, stands alone in the organic kingdom, as other types do.

"The elder Agassiz long ago tried to prove that the well-marked areas of geographical distribution of mammals have their special kinds of men; and, though this doctrine cannot be made good to the extent which Agassiz maintained, yet the limitation of the Australian type to New Holland, the approximate restriction of the negro type to Ultra-Saharal Africa, and the peculiar character of the population of Central and South America, are facts which bear strongly in favour of the conclusion that the causes which have influenced the distribution of mammals in general have powerfully affected that of man."[2]

It is a question of one or several centres and of single or multiple origins.

§ 288. Man as a Separate Creation.

Much has been said and written as to man's origin, career, history, and destiny. Is he an original creation (type), or is he evolved from a soft-bodied mollusc—the oyster, for instance—or from the most elementary of all animal forms, namely, the monad? Was he a highly intellectual being from the first, or has he, as the *evolutionists* put it, slowly accumulated intelligence in his countless transitions through endless animal forms in infinite time? Has he progressed or retrogressed through the ages, or partly the one and partly the other? Is he the progenitor of the savage, or is the savage his progenitor? Does he represent in himself a being wholly apart and independent, and not resting, directly or indirectly, upon other members of the animal series? Is he a made-up, conglomerate animal with descendants and offspring? Is he the *ne plus ultra* of the human family, all-sufficient in itself, or is there something beyond?

These questions are more readily asked than answered, and require separate consideration.

Considering the enormous antiquity of man, and his permanency as a created type, I am disposed to regard him as an original creation. He has not changed in the least physically for six or seven thousand years—the historical period—and, as there were cities and civilisation long anterior to these dates, his advent on the earth as an intellectual being must be indefinitely antedated.[3] If man was civilised from an indefinitely remote period, and has not changed physically for a great many thousand years, the argument for his being an original creation, and not an evolution, is very greatly strengthened. It would have been quite as easy to the Creator to make man

[1] Fraipont and Lohest, "La Race humaine de Neanderthal, ou de Canstatt, en Belgique." (*Archives de Biologie*, 1866.)

[2] Huxley, op. cit., 325.

[3] Research in Egypt has recently revealed earlier strata of civilisation than a few years ago were supposed to exist. M. Capart's volume ("Primitive Art in Egypt," 1905) exhibits a practically continuous series of ornamental utensils and sculptured monuments connecting the neolithic age with Pharaonic times. It is curious to observe that the flint instruments of Egypt were of a very high standard of workmanship, and that art is of immemorial antiquity in that ancient land. Further, the continuity of styles is highly remarkable. Hence, the question of the origin of Egyptian art has taken a new form. Hitherto the archæologists have assumed that civilisation must have been imported into the Nile valley from without, and have endeavoured to discover the country from which it was brought, but now there is substantial evidence that much of it was, to all intents and purposes, indigenous, the earliest finds being linked by continuity of style with the latest, though evidences of foreign influences are, of course, indubitable. . . . The objects of which M. Capart's volume treats are ascribed to dates lying between 7000 B.C. and 4000 B.C., and the connecting link between prehistoric times and the first dynasty is supposed to have been found in Petrie's excavations of the small town of Abydos. M. Capart ascribes the neolithic civilisation to a Libyan race, possibly of European origin. (*The Queen*, July 22, 1905.)

as we know him historically, and as he is at the present day, as to have dragged him through every animal form from the lowest to the highest. *Man as a product of evolution* is, in a sense, more wonderful *than man as an original creation*. Both methods of production, however, are equally simple to the great First Cause. The evolutionary idea of the production of the organic kingdom—man included—does not necessarily exclude the idea of a Creator or First Cause. Those who advocate the evolution of man from the lowest conceivable living forms found their case upon three different lines of argument: (*a*) embryonic development, (*b*) comparative anatomy, and (*c*) palæontology. They maintain that man is the product of a living protoplasmic mass (a cell), which grows and differentiates to an almost unlimited extent. They ignore the Giver of Life, and the Guiding Power behind the cell which makes the growth and differentiation possible. They have to invoke the aid of spontaneous generation, which, as far as science is concerned, is an *ignis fatuus*.

They assert that all animals lead up to man, that he has all the animals for ancestors, and that he represents all animals, past and present. They leave out of consideration the idea of type in time and space; they advocate endless modifications and fluctuations in the production of man, and, characteristically, pay no attention to the extraordinary permanency and persistency of man on the earth. They take no account of the fact that man has not changed physically for six or seven thousand years. They claim unlimited modifications in unlimited time for the production of man, but they do not succeed in explaining the *stasis* of man as a permanent form. They also fail to make good or to produce even fragments of quite a plethora of, so-called, connecting forms, otherwise known as missing links.[1]

They refer the origin of man to the end of the Tertiary period, when, according to them, he sprung from the anthropoid apes forming two geographical groups—the Asiatic and the African. This, I need scarcely remark, is mere theory and guessing; no actual remains of man having been found in Tertiary times.

It avails little to say that the anthropoid ape—the giant gorilla, for example—and man have a common or even an identical structure, as is done in the following passage quoted by Professor Haeckel: "The same 200 bones, arranged in the same way, form our internal skeleton; the same 300 muscles effect our movements; the same hair covers our skin; the same groups of ganglionic cells compose the ingenious mechanism of our brain; the same four-chambered heart is the central pump of our circulation."[2]

All this does not prove that the gorilla and man are one and the same animal, or that man has an anthropoid ape for his ancestor. It only proves that man is not dissociated from the higher animals (the anthropoid apes included), and that he is formed on a common and persistent type. His permanency as a living form excludes the idea of his being descended from a long line of apes by endless modifications which have *change* and *not permanency* for their object. In the inorganic kingdom there are uniformity and common laws at work, and the same is true of the organic kingdom. The fact that man is not disrupted or dissociated from the other members of the animal kingdom does not prove that he is a conglomerate in which every member of the animal kingdom is represented.

Professors Huxley and Haeckel attach great importance to embryology and comparative anatomy in settling the knotty problem of man's origin.

Professor Huxley[3] thus states the embryological argument: "The dog, like all animals, save the very lowest (and further inquiries may not improbably remove the apparent exception), commences its existence as an egg: as a body which is, in every sense, as much an egg as that of a hen, but is devoid of that accumulation of nutritive matter which confers upon the bird's egg its exceptional size and domestic utility; and wants the shell, which would not only be useless to an animal incubated within the body of its parent, but would cut it off from

[1] The permanency of form claimed for man is not confined to him. It extends to a very large number of plants and animals whose histories have been traced. As Mr. Carruthers has pointed out, the willow (*Salix polaris*) has not changed for several thousands of years.

Professor Huxley in his lecture "On the Hypothesis of Evolution," in discussing the permanency of type, remarks: "The progress of research has supplied far more striking examples of the long duration of specific forms of life than those which are furnished by the mummified ibises and crocodiles of Egypt. A remarkable case was found in the neighbourhood of the Falls of Niagara. In the immediate vicinity of the whirlpool, and again upon Goat Island, in the superficial deposits which cover the surface of the rocky subsoil in those regions, there are found remains of animals in perfect preservation, and among them shells belonging to exactly the same species as those which at present inhabit the still waters of Lake Erie. . . . We are fairly justified in concluding that no less a period than 30,000 years have passed since the shell-fish, whose remains are left in the beds to which I have referred, were living creatures."

The permanence of type referred to by Carruthers, Huxley, and others is emphasised on the tombs, temples, monuments, &c. of Egypt, as I myself can testify; these display bas-reliefs of quite a large number of insects, fishes, reptiles, birds, and mammals identical with those living at the present day. Many of the bas-reliefs in question date back at least six thousand years. The permanency of type in plants and animals as a whole, it need scarcely be added, *is opposed to evolution*.

[2] Against this Professor Goodsir states: "The human body presents a whole series of perfected arrangements of structure, bearing immediately on the higher conscious or rational principle of man—arrangements which are deficient in all apes alike, and which thus collectively, by their absence, distinguish all the apes from man corporeally as precisely as their instinctive form of consciousness separates them from man psychically.

"All organic science, but more especially its anthropological department, inosculates with the higher forms of truth and belief so intimately and extensively as to render the discussion of the higher questions as to organisation absolutely futile, if dissociated from their co-ordinate department of psychological, moral, and religious truth and belief."

[3] "Man's Place in Nature." London, pp. 82–90.

access to the source of that nutriment which the young creature requires, but which the minute egg of the mammal does not contain within itself. . . . There is not much apparent resemblance between a barn-door fowl, and the dog who protects the farm yard. Nevertheless the student of development finds, not only that the chick commences its existence as an egg, primarily identical, in all essential respects, with that of the dog, but that the yolk of this egg undergoes division—that the primitive groove arises, and that the contiguous parts of the germ are fashioned, by precisely similar methods, into a young chick, which, at one stage of its existence, is so like the nascent dog, that ordinary inspection would hardly distinguish the two. The history of the development of any other vertebrate animal, lizard, snake, frog, or fish, tells the same story. There is always, to begin with, an egg having the same essential structure as that of the dog; the yolk of that egg always undergoes division, or *segmentation*, as it is often called; the ultimate products of that segmentation constitute the building materials for the body of the young animal; and this is built up round a primitive groove, in the floor of which a notochord is developed. Furthermore, there is a period in which the young of all these animals resemble one another, not merely in outward form, but in all essentials of structure, so closely, that the differences between them are inconsiderable, while in their subsequent course they diverge more and more widely from one another. . . . Thus the study of development affords a clear test of closeness of structural affinity, and one turns with impatience to inquire what results are yielded by the study of the development of man. Is he something apart? Does he originate in a totally different way from the dog, bird, frog, and fish, thus justifying those who assert him to have no place in nature and no real affinity with the lower world of animal life? Or does he originate in a similar germ, pass through the same slow and gradually progressive modifications, depend on the same contrivances for protection and nutrition, and finally enter the world by the help of the same mechanism? The reply is not doubtful for a moment, and has not been doubtful any time these thirty years. Without question, the mode of origin and the early stages of the development of man are identical with those of the animals immediately below him in the scale; without a doubt, in these respects, he is far nearer the apes, than the apes are to the dog."

Professor Haeckel[1] supplements the foregoing as follows: "There is a great phylogenetic significance in the perfect agreement which we find between man and the anthropoid apes in these important features of embryonic circulation, and the special construction of the placenta and the umbilical cord."

The blood of certain mammals can be injected into the veins of other animals, not specifically allied, without harm, and the vaccine lymph of the cow can be introduced into the human circulation without any permanent bad effects. The ox, certainly, cannot be said to be nearly related to man.

The comparative anatomy and palæontological arguments adduced by Professors Huxley and Haeckel in favour of evolution and the descent of man from the apes are to be found in their numerous works, and are too extensive to be quoted here. I may, however, direct attention to an argument which is quite overlooked by both of those authors.

While quite admitting the remarkable structural resemblances revealed by embryology and comparative anatomy in animals, regarded as a progressive ascending series, I nevertheless maintain that neither embryology nor comparative anatomy provides the necessary facts to establish a rational doctrine of evolution; evolution, be it understood, being the continuous manufacture of higher from lower forms, by a series of accidental, trifling modifications extending over long periods. The embryologists and comparative anatomists who advocate evolution leave out of sight four most important factors:—

1. They begin with a living cell, but do not account for life.
2. They do not explain by what power animals differentiate.
3. They fail to show how animals are arranged in an ascending progressive series, and,
4. They have no explanation to give of the permanency of leading types.

Their starting-point, as indicated, is a *living* cell. The non-believer in evolution naturally and very properly asks whence it came? To this the advocates of evolution can give no satisfactory reply. They lean on the broken reed of "spontaneous generation," which exact science discards.

They state that the impregnated cell or ovum in due course breaks up and divides by a process of segmentation, to form tissues and organs, and that in the early stages of development the fish, the reptile, the bird, and the mammal remarkably *resemble* each other, but that as development proceeds, and the adult form is reached, they remarkably *differ* from each other. They are here on the horns of a dilemma, as they can neither explain the resemblances nor the differences. The non-believer in evolution as a physical process inquires, and rightly, what power other than the Creator or First Cause can direct the growing cell to become a fish, a reptile, a bird, or a

[1] "The Evolution of Man," vol. i. London, 1905, pp. 388–401.

mammal respectively? It is quite plain that design, law, and order are at work. Accident or chance can have no place in the production of organised beings. No number of secondary causes can take the place of the First Cause. In the egg, in a latent but potential form, those properties and qualities exist, which, under the operation of a First Cause, differentiate and develop into the several kinds of animals referred to. It is not conceivable that from one and the same egg all the varieties of animals proceed. Eggs differ infinitely in ultimate composition, and the difference in the eggs corresponds exactly with the number and kind of animals produced from them. The differences referred to cannot be demonstrated by chemistry or by the microscope, but that they exist is indisputable in the light of reason and common sense. An elephant cannot be produced from the egg of a mouse, a whale from the egg of a porpoise, a horse from the egg of a lion, or a rhinoceros from the egg of a crocodile. It matters not that all these animals resemble each other in their early stages of development. In the adult state they are widely and strikingly divergent. They are separate and conditioned existences; they have their limits defined in time and space. Mere resemblances in tissues, structures, organs, and individuals, do not settle the subject of evolution in the affirmative, and it is here that both embryology and comparative anatomy fail. These sciences provide no sure foundation upon which to rear a philosophical evolution. They fail at the outset, and they fail all through. They do not divine the true nature of the egg upon which the theory of evolution, according to them, is based. No number of resemblances, and no number of allied forms, can make the original egg identical in all its parts and particles; neither can they account for the fact that eggs, apparently homogeneous and uniform in every direction, produce animals which at once reveal numerous points of resemblance *and numerous points of dissimilarity;* the differences, on the whole, outweighing the resemblances. I directed attention to this subject as far back as 1873,[1] and nothing said or written since then has caused me to change my views.

My contention, that impregnated eggs differ fundamentally from each other, and that they are not simple but complex, originally enunciated in 1873 as a rejoinder to Professor Huxley's "protoplasm or physical basis of life" and Professor Lionel S. Beale's "bioplasm," has been confirmed by Professor August Weismann in his paper, "On Germinal Selection as a Source of Definite Variation" (1902). Professor Weismann thus states the case from his point of view: "There *must* be contained in the germ, parts that correspond to definite parts of the complete organism, that is, parts that constitute the reason why such other parts are formed. It is conceded even by my opponents that the reason why one egg produces a chicken and another a duck is not to be sought in external conditions, but lies in a difference of the germinal substance. Nor can they deny that a difference of germinal substance must also constitute the reason why a slight *hereditary* difference should exist between two filial organisms. . . . But the fact that every complex organism is actually composed of a very large number of parts independently alterable from the germ, follows not only from the comparison of allied species, but also and principally from the experiments long conducted by man in artificial selection, and by the consequent and not infrequent change of only a single part which happens to claim his interest. . . . The assumption thus appears to me irresistible, that every such hereditary and likewise independent and very slight change of the body rests on some alteration of a *single* definite particle of the germinal substance, and not, as Spencer and his followers would have it, on a change of *all* the units of the germ. If the germinal substance consisted wholly of like units, then in every change, were it only of a single character, *each* of these units would have to undergo exactly the same modification. Now I do not see how this is possible. . . . *The differences that I put into the whole germ, Spencer and his followers are obliged to put into every single unit of the germinal substance.* . . . The person who fancies he can produce a complex organism from a *really* simple germinal substance is mistaken; he has not yet thoroughly pondered the problem. The so-called 'epigenetic' theory with its *similar* germinal units is therefore nought else than an evolution theory where the primary constitutional elements are reduced to the molecules and atoms—a view which in my judgment is inadmissible. A *real* epigenesis from absolutely *homogeneous* and not merely *like* units is not thinkable."

While Professor Weismann and I agree as to the complex nature of the impregnated ovum, I am by no means in agreement with him as to his theory of "germinal selection as a source of definite variation." As a matter of fact, I am opposed to selection in all its forms. The only selection I recognise is that made by the Creator or First Cause.

Embryology and comparative anatomy, while they succeed in establishing resemblances in animals up to a point, do not attempt to explain or account for them. They take refuge in secondary causes and so-called "natural selection." I decline to substitute secondary causes and chance for a First Cause and design. I further decline (and I do so in no carping spirit) to attach any importance to natural selection as defined by Mr. Darwin and his disciples in the production of true species. As I have explained in previous sections of this work, no animal, high

[1] "On the Relation of Plants and Animals to Inorganic Matter, and on the Inter-action of the Vital and Physical Forces." (*Edinburgh Medical Journal*, 1873.)

or low, can select or determine what parts of its organism shall grow or cease to grow in particular directions. It has no power to perpetuate its good properties and qualities and to suppress its bad ones. This can only be done by a selector or director outside the animal itself, and this selector and director is undoubtedly the First Cause. There is no such thing as so-called *natural selection* in the sense in which it is at present employed. There is an *artificial selection* when a breeder of stock exercises his intelligence and breeds from animals having peculiarities, which peculiarities he wishes to perpetuate ; but there is no such thing as natural selection, *if the First Cause be suppressed.* To take an example. Man, who is the most intelligent animal in existence, cannot by willing or wishing alter any single structure in his body. He cannot cause to grow, or prevent from growing, a single hair of his head ; he cannot add to, or take from, his stature ; he cannot make or suppress any of his organs ; he cannot alter his hard or soft parts ; he cannot produce or suppress any of the bones, or other structures, with which he was originally provided. If man, with all his intelligence, will-power, and tact, can alter nothing in himself and by himself, it goes without saying, that no animal lower than man can do so. The same is true of plants. Natural selection, if it means anything, means God selection. Selection implies and necessitates a selector. Neither the plant nor the animal can select for themselves ; the selector must be outside both. When a male selects a particular female, or the converse, the selection is not made with a view to producing or perpetuating peculiarities in either, but in accordance with a general law, which has for its object the equalising of the type. In this way dark people marry fair people, tall people short people, stout people thin people, self-willed people the nervously weak, &c. The First Cause is behind and outside even this form of selection. In plants and the lowest kinds of animals, sexual selection cannot possibly take place apart from a First Cause.

If embryology and comparative anatomy cannot account for life and for differentiation ; if they can only establish resemblances which they cannot explain ; and if, at the same time, they altogether fail to account for acknowledged differences ; it follows that they cannot possibly furnish reliable data for even a provisional theory of evolution. The mere enumeration of points of resemblance and difference in animals, apart from a satisfactory explanation of the causes which produce them, can serve no good purpose.

The said resemblances and differences are cardinal points. On these the great subjects of types and classification are based. According to the theory of evolution, living things are eternally changing. There is no fixity, no permanence of type. But, evolution notwithstanding, there is type and there is permanence of type. Some animals, according to Mr. Huxley, have not changed perceptibly for 30,000 years ; and similar remarks may be made regarding certain plants. If evolution necessitates continual change, and it can be shown that certain plants and animals do not change for enormously long periods, or not at all, evolution, even as a working hypothesis, is inadmissible.

Before leaving this subject it may be well if I direct attention to the extraordinary elaboration of the tissues and organs in man as compared with those of the lower animals.

Having very carefully injected, dissected, and prepared every part of the human body on several occasions, and also the bodies of apes and other animals for preservation in the Hunterian Museum of the Royal College of Surgeons of England, London, I can testify that all the tissues and organs of man are more complex (in many cases matted together), involved, and elaborate than those of the brute creation. This is especially true of the nervous system, brain, and sense organs. They are, as a consequence, much more difficult to dissect. The cellular tissue and muscles of an ape, for example, give comparatively little trouble. Those of man, on the contrary, try one's patience to the utmost. What is true of the cellular tissue and muscles is true of all the other parts. This is a point which only the highest forms of dissection can establish, but it is one which I regard it as important to make. My contention is, that man has warrant in his bodily structure—especially in his nervous system, brain, and sense organs—for the extraordinary powers possessed by him. As function, in every instance, follows structure, this perfection of bodily configuration in man is a necessity. The perfection referred to is revealed not only by the scalpel, but also by the highest powers of the microscope. To those interested in anatomy I would recommend a visit to the Hunterian Museum of the Royal College of Surgeons of England, London, where hundreds of my dissections, permanently preserved in spirit, can be seen.

The late Professor John Goodsir, of Edinburgh University, who holds a foremost place as an anatomist, physiologist, pathologist, and philosopher, in a remarkable series of lectures on " The Dignity of the Human Body," [1] held strongly to the idea that man was not evolved, but that he was a special creation, and differed from the brute in many important respects.

The lectures in question dealt with the following momentous subjects : the Nature of Animality, the Essence of Humanity, the Erect Position in Man, the Upper Limb in Man, the Integument and Organs of Sense and Speech in

[1] "The Anatomical Memoirs of John Goodsir, F.R.S., late Professor of Anatomy in the University of Edinburgh," vol. i., 1868, pp. 207–280.

Man, Skull and Brain in Man, Teleology and Morphology, the Position of Man in the Scale of Being, Retrogressive Man, Progressive Man, &c.

Professor Goodsir, as was his wont, enunciated his views with great clearness and force in a series of propositions. These, it appears to me, are so important, and represent the views of so many educated persons, that I feel it to be at once a privilege and a duty to give liberal extracts from them. He says :—

"The human race is characterised by the great varieties which exist between different peoples. The question is not unfrequently asked, Was not man originally savage ? Was he at one time near the brutes ? I believe that man was not originally savage, and that the less civilised races are not undeveloped but degraded forms. Man, in virtue of possessing a spiritual element, stands alone amongst the organised beings of the globe. The existence of this element associates the being possessing it with the spiritual world. An organism adapted to a spiritual end, and capable of acting in space in the most perfect manner, must be more highly developed than one not so adapted. . . . The psychical principle in man and animals, although immaterial, is distinguished from the spiritual in man by the immutability of its powers and attributes, and is especially adapted to each species. The pneuma, or spiritual element in man, also immaterial, and only recognisable by its manifestations through consciousness, is strictly co-ordinate with man's sphere of action on earth and his future destination. It is, nevertheless, subject to his will. Not only is the individual economy of the animal strictly provided for, but by the same agency the purpose of the animal in creation is secured. . . . The welfare of the entire human constitution, organic as well as spiritual, can only be conditioned by a proper action of the spiritual element. This has always to be remembered in looking for an explanation of all the varieties of race and of individual personal character. Why, then, should man alone, of all the living beings on this globe, have been left so unfettered that his welfare should depend on his own choice ?

"Herein lies the great mystery of humanity, on the existence of which depends that *religiosity* which is characteristic of every form of the human race. The consciousness of untruth, and of error in some form or other, exists in every modification of man ; and it is equally certain that all the vicissitudes of human history, and all the distress against which man has had to struggle, have been directly due to his tendency to untruth, and his liability to error. . . . Man lost his primitive form of economy, and his more favourable conditions of welfare, by the erroneous use of his higher or spiritual principle, by his preference of untruth to truth, of error to rectitude, and thereupon humanity became subject to all those ills which have chequered its progress. . . . We are bound to guard ourselves against the conscious or unconscious assumption, that the development of humanity can be legitimately or safely investigated as an anthropological subject, without reference to the primitive condition of man as presented to us in the revealed record. As we deduce all the personal and social misery of man on this globe from his erroneous choice of action through neglect of his higher principle of belief, so in like manner we are bound to attribute to the same source the causes which have produced all the so-called forms of savagism and imperfect forms of human structure as presented to us in our ethnological or archæological inquiries. . . .

"Any fundamental question in anthropology must necessarily be based on three convergent lines of evidence —the physiological, psychological, and theological. . . . There are sufficient grounds for believing primitive man to have been, not a savage, but man in his originally perfect form, fitted by the undegraded character of his spiritual element for immediate converse with his Creator, in Whose image his spirit had been framed, and by Whose instruction he was initiated in regard to his moral and spiritual nature ; guided to the use of his faculty of speech, and to the application of his intellectual powers in the investigation and appropriation for his own welfare of the objects and living beings by which he was surrounded.[1] . . . We must, in my opinion, hold that the phase of humanity in which we ourselves live is a secondary phase, in which man has lost the completeness of his primitive economy, and his more favourable primitive conditions of existence, as evinced in the degraded and helpless condition into which the greater part of humanity in all ages, as well as in the present, has fallen, and not less so, in the unsatisfactory aspect which our modern so-called civilisation presents ; and that, therefore, had humanity in its present phase been dependent on its own resources, as the animal is, no section of it could have resisted the retrogressive tendency, or have opposed the obstacles to that progression on which the hopes of man are fixed. . . . We are brought to see in the present phase of humanity a progressive series of advancing forms of society, a series continually increased by collateral additions, but extending backwards uninterruptedly to the commencement of the phase. The twofold retrogressive and progressive character presented by the history of man is from every point of view peculiar, and completely distinguishes his economy from that of any animal, and at the same time constitutes as important a feature in his physiological as in his political and moral aspects. . . . The change in

[1] It may not be out of place to refer to the work, "On the Antiquity of Intellectual Man," by Professor C. Piazzi Smyth, in which a conclusion similar to that expressed in the text has been arrived at from the consideration of a different line of evidence to that employed in these lectures.

the economy and welfare of man was the result of an act which involved a breach of his moral principle. . . . We must hold, that as the psychical is the primary and controlling element which secures the welfare of the animal, and fulfils its purpose in nature, so, on the other hand, the spirit in man is that element in his economy on which his entire welfare depends. . . . The essence of humanity consists in the human organism, that is, the combined physiological and psychical element, co-ordinate with, and subject to, the control of a spiritual element. The essence of humanity, in fact, consists in a spiritual element of which the co-ordinate organism is the instrument. . . . If man were, as some suppose, at the head of the animal kingdom, some ape should be found to stand immediately beneath him; but the apes are all related to each other, and grouped around a type which is that of an ape.

"As I already stated, the two aspects presented by humanity in its present phase are retrogressive and progressive, and are essentially dependent on moral causes. . . . As man was placed on this earth to fill and to subdue it, it is evident that, in so far as he has permitted such cosmical or material influences to detract from his spiritual efficiency, he himself is to blame, and that it is now his duty, in his present phase, to develop his progressive form under the conditions provided for that purpose."

Professor Goodsir's estimate of the past and present of man is greatly enhanced by his intimate knowledge of the animal kingdom as a whole. His observations on animality are entitled to the greatest possible consideration. He states: "A species can only exist over a geographical area having certain conditions of geological structure, of climate, and of animal and vegetable forms.[1] The characters of the living economy of an animal species may, indeed, become more or less modified, or the number of its individuals may diminish, in accordance with modifications in the cosmical conditions of its area of distribution. But there is a limit to such permitted modifications of specific character, and if the cosmical conditions of its existence pass these limits, the species disappears. . . . Each species of animal was directly created for its proper area. . . . The conscious element of an animal is virtually the animal itself, for it is that, failing which, the body of the animal would have no existence. It is that element in the animal constitution which is immutable. For although the constituent parts of the corporeal structure of the horse, dog, or pigeon, along with the instincts co-ordinate with those parts, may, by certain natural or artificial rearrangements of the specific conditions of the animal's existence, undergo very great modifications, nevertheless, the fundamental attributes of its conscious element—which collectively constitute a horse, dog, or pigeon—remain unaltered, whether the animal has assumed a degraded or an elevated type of its specific form.

"An animal is adapted to its geographical area by the endowments of its conscious principle, of which element its corporeal structure is the mere instrument.

"Every animal reacts on the area which it inhabits; that reaction being, in fact, the final purpose for which the animal was created. . . . Thus, it is indirectly engaged in furthering its Creator's plan. . . . When a species ceases to exist, we must consider its disappearance as the result, not of a mere struggle for existence with other animal forms or with cosmical conditions, nor of insufficient adaptivity to such extent of altered conditions of life as its specific endowments admit, but as the more or less direct result of the law impressed upon its instinctive consciousness, in virtue of which it must cease to exist, when no longer supplied with the conditions on which its activity and faculties may be exercised through the instrumentality of its corporeal vehicle. . . . There can be no question as to the existence in the animal of a principle allied to our own human consciousness. This is admitted by common consent. Every unbiassed observer who has studied the actions of the various forms of animals, from the protozoon upwards, must feel impressed by the manifestations presented of an ascending series of forms of consciousness; a series co-ordinate with the series of structural forms in which their presence is manifested. . . . The mental processes in the animal are simple and direct; and, moreover, it cannot transgress their laws. . . . All the conditions of the conscious principle of an animal, whether they be induced by objects from without, or originate in the inner or proper processes of the conscious principle itself, or exhibit themselves under the aspect of a will, would thus appear to be as fully predetermined in the economy of the animal's specific conscious principle, as are the specific structures provided for its corporeal economy. . . . As in the animal, so in man; his entire economy must be co-ordinate with his area—or, as we must term it in his case, sphere of action.

"Man has not been created for any area of a given geological, climatal, or phytozoological character. He inhabits the entire globe.

"The extension of man over the globe has been provided for in the superiority of his psychical, and consequently of his corporeal, endowments. . . . Tradition, history, and revelation, the three sources from which the anthropologist derives his most essential facts, combine in assigning a locality in the North Temperate Zone as the original area of man. We must assume, therefore, that a temperate zone affords more immediately the material conditions of human life and welfare. Nevertheless, man has gradually extended the area of his habitation, or temporary occupation, into the Torrid and Arctic Zones, and will at length be enabled, if not continuously to inhabit, at least

[1] For various views on species see p. 682 of the present work.

to connect and appropriate for his benefit every portion of the earth's surface, and so to fulfil his Creator's reiterated command to 'be fruitful and multiply, and replenish the earth, *and subdue it;* and have dominion over the fish of the sea, and over the fowl of the air, and over every living thing that moveth upon the earth.' . . . Man, like the animal, not only finds his subsistence in his geographical area, but also reacts upon it. . . . The clearing of forests, the recovery of dry surface by coast and river embankment and by draining, the securing of moisture by irrigation, are processes which not only prepare the surface for agricultural produce, but induce at the same time an appropriate change of climate. The changes of surface and climate, induced by human agency, tend to check the productivity of certain vegetable and animal forms; or by entirely removing their proper conditions of life, cause the local or general disappearance of others. The formation of roads, of bridges, of aqueducts, of canals, of railroads, of telegraphs, merely presents successive phases of that development of the surface of the globe due to man—a development which is affected under his self-conscious or rational agency, in obedience to his Maker's command to 'replenish the earth, and subdue it.' . . . While the animal is merely enabled, with its specific strength, to provide its means of subsistence, man is enabled, as he advances in his work of subjugating the earth, to avail himself of external material force to effect his successive purposes. Under the guidance of his rational intelligence, he proceeds on mechanical principles; he collects and concentrates, for the ends he has in view, the forces involved in gunpowder and steam, and thus making his way into the interior of the earth in search of its mineral wealth, modifies its surfaces in accordance with the requirements of each locality. . . . The human constitution involves in itself, and secures for man, two guiding principles of action, not possessed by the animal—the faculty of thought, and the moral faculty—in virtue of both of which, but primarily of the latter, he is fitted to fulfil the conditions of a religious being. *Finally*, the economy of man would be incomplete, his various endowments could not be efficiently applied by him, were he destitute of speech. The varied and ever-varying development of language is one of the most remarkable results of the peculiar constitution of humanity. . . . With an animal body and instincts, man possesses also a consciousness involving Divine truth in its regulative principles. But along with this highly-endowed consciousness, the human being has been left free to act either according to the impulses of his animal, or of his higher principle. The actual history of humanity, of its errors, its sufferings, and its progress, is the record of the struggle between man's animal and Divine principle, and of the means vouchsafed by his Creator for his relief."

Not less interesting and instructive are Professor Goodsir's remarks on the Erect Position and Upper Limb in Man, his Integument, Organs of Sense and Speech, and his Skull and Brain. To these I will refer very briefly in the order stated in Goodsir's own words: "The erect position is that in which the body is placed when all the parts are arranged so as to occasion the least amount of exertion. In it the spine is erect and the eyes look horizontally forwards, the arms being pendulous. . . . In the normal position of the human body the axis of the vertebral column is vertical. No animal form of vertebral column can be elevated into the perpendicular position. In apes, in the so-called upright position, the axis is oblique; and when these animals are on all fours, nearly horizontal. In birds, also, it is oblique. In quadrupeds, horizontal. . . . In no form of animal vertebral column are the secondary curvatures so highly developed as in the human, and no animal possesses the lumbar curvature. . . . The non-possession of a separate lumbar curve by animals is a very remarkable fact; in the proper monkeys no such curve exists. Lateral curves are feebly marked in the animal spine. . . . No mammal possesses vertebral and trunk muscles so fully differentiated and so spirally arranged as in man. The muscles of the trunk, obliqui, serrati, &c., are arranged in continuous corkscrew-like spirals around the body, as was first pointed out by E. Weber. The peculiar spiral attitudes into which the human body can be thrown are explained by the spiral curve of the vertebral articular surfaces, and the spiral arrangement of the muscles. No mammal can throw its trunk into those spiral curves which subserve the balance of the human frame, and confer the peculiar grace and expression of its movements. . . . The human haunch-bone is the only form of haunch-bone adapted for the erect position. . . . The proper muscles of the thigh are in man principally devoted to the balance of the trunk on the hip-joint. The corresponding muscles in the animal are chiefly devoted to the propulsion of the body. . . . In no animal are the tibia and fibula collectively so fully developed and adapted to the actions of the foot, as in man. . . . The human knee-joint is the only knee-joint which admits of complete extension. . . . The human foot is a plantigrade food, and the hallux forms its axis. . . . The human foot is a tripod, the heel and inner pad being its fixed points, the outer pad the adjustable point. The human ankle joint is the only complete ankle joint; it alone possesses a complete extensor area. . . . The structure in the ape corresponding to the human foot is a foot-hand, or *manuped*. Presenting the fundamental type of the foot of the mammal, it is so modified as to form a clasping instrument. In certain respects it more nearly resembles that only perfect hand, the human hand, than the so-called hand in the anterior limb of the ape itself. . . . The erect attitude in man is the principal condition of that high privilege which he enjoys, of the free use of his upper limbs, in the performance of higher functions than the locomotory.

"The upper limbs in man are the immediate instruments, under the guidance of his rational consciousness, of that power with which he is invested over material nature. Set free by the peculiar construction of his lower limbs and spinal column, and presenting a peculiar organisation of their own, his upper limbs act freely in all those relations of space involved in the human conception of matter. . . . The human hand is the only perfect or complete hand. In no other is there such a freely movable thumb, capable of such complete opposition, which is provided for by the saddle-shaped surfaces of its carpo-metacarpal joint. The opposition of the thumb must be distinguished from the opposition of the great toe, the tarso-metatarsal joint of which admits of movements in one plane only. . . . The human hand may be hollowed into a cup, and it can grasp a sphere. It is an instrument of manipulation co-extensive with human activity.

"The hand of the ape is an imperfect hand, with clearly defined points of difference and inferiority, when compared with the human hand. Its thumb is short and feeble, and the axes of the metacarpo-phalangeal articulations of the fingers are inclined towards the thumb. It can embrace a cylinder, as the branch of a tree, and is principally subservient to the arboreal habits of the animal. . . . The human foot and the ape's foot are morphologically feet, but the human foot is not only morphologically but teleologically a foot; and, moreover, the only perfect and complete foot, whereas the ape's foot is teleologically a hand. . . . Man is not only alone in his erect position, but he alone can lay himself in the prone and supine positions. This he is enabled to do by the antero-posterior compression of his thorax."

Referring to the Integument and Organs of Sense and Speech in Man, Professor Goodsir observes: "The integument may serve as a means of preserving the general form, as a protection from external influences, as an excretory apparatus, as an absorbent medium; and lastly, as an arrangement for placing the nervous system in relation to external objects. . . . In no animal do we find the integument so harmoniously developed, for all its special ends, as in man. . . . The sensibility of the human skin is its most important physiological feature. No animal displays a cutaneous nervous system so developed as the human. . . . The human skin is characterised by the precision of its tactile sensibility, as well as by its full physiological relations to temperature, pressure, and muscular action. In no animal are the tactile arrangements on the distal portions of the limbs so fully developed as in man. No form of ape exhibits the same complex and relatively minute arrangement of tactile ridges as in the human hands and feet. . . . The human integument is directly developed in reference to the intellectual and emotional phases of his constitution. . . .

"The distribution and character of the hair in man is highly characteristic, and indicative of the distinct and peculiar nature of his economy. In the higher animals, hair is provided for protection and warmth. It serves more varied ends in the human economy. . . . The principle which determines the distribution of hair on the human body, appears to be based on the higher form of the emotional and æsthetic phases of the human constitution. . . . In no animal is the direction or arrangement of the hair so complex as in man."

The following are briefly Professor Goodsir's views regarding smelling, tasting, seeing, hearing, and voice production: "The organs of smell and taste in man are distinguished anatomically by their apparent feebleness of development, and physiologically by their much more extended spheres of action. . . . While the sense of smell in man is apt to be blunted by his habits of life, no animal apparently possesses an appreciation so extensive of odours in general. The structural arrangements which subserve the sense of taste are not confined to the tongue, but extend along the fauces and palate. All those arrangements in the tongue, fauces, and palate, which adapt those parts to their functions in the process of digestion, adapt them also to the sense of taste. Of the special adaptations of those parts in man, the most important are the great tactile sensibility of the tongue, and the horizontal position of the mouth. There is, probably, no difference in the sense of sapidity, or taste proper, of man and the higher animals, except, perhaps, in its delicacy in man. . . . Many of the sensations we are in the habit of regarding as due to taste are probably merely modifications of touch. . . . The eye and ear in man, being more immediately associated with his higher interests, present special arrangements. . . . The human orbit presents the most elongated form, and most extended outer wall. These orbital peculiarities of the human skull are special provisions for a greater freedom and extent of visual directions, but more especially to provide for a more perfect binocular vision. The semicircular canals of the organ of hearing are connected with the sense of direction of sound. They are situated at right angles to each other. No one is situated precisely right and left to its fellow, or to the axis. . . . The horizontal position, which appears essential to the efficiency of the semicircular canals, and is a marked feature in man, is provided for in the head of the animal by the same changes which render its visual axis horizontal.

"The human larynx is characteristically simple and complete in its arrangements. Its special characters are the mobility of the arytenoid cartilages, the complex curvatures of the crico-arytenoid articulations, and the total

absence of any superadded acoustic arrangement. The perfection of its structure is evinced in the purity of its tones, and the extent of its intonation.

"As the instinctive consciousness of the animal provides each individual of the species with the faculty of acting in co-operation with its fellows, the social or other instrumental signs or signals by which direct intercommunication is effected, are comparatively simple. As human action, again, is essentially dependent on man's rational consciousness, it becomes an important condition of his welfare that a portion of his corporeal mechanism should be such as to supply him with a system of intercommunicating signals co-ordinate with the universality of his conscious acts.

"As a special modification of the upper end of the air tube is provided as the instrument of voice in man and the mammalia, so in like manner the mechanism of speech is provided for man alone in peculiar modifications of his buccal, pharyngeal, and nasal chambers.

"The mechanism of speech is such that certain voluntary dispositions of its parts induce in the air generally, during expiration, certain sounds termed articulate sounds, which may be mute or unvocalised, that is, unaccompanied by laryngeal action, as in the whisper, or intoned as in ordinary speech, which is produced in co-ordination with the voice. . . . The human pharynx and fauces are peculiar in the shortness and mobility of the uvula, which is the chief framer of vocal sounds. . . . Articulate sounds are merely the elements, by the combination of which the composite sounds, or words, which actually constitute a language are formed. . . . Speech, although based on the conscious principle of humanity, and provided for in an instinctive corporeal mechanism, is actually acquired by a combined course of self-tuition and education.

"In learning to speak, the child is supplied, through its organs of hearing, with the radicles of its native language. . . . Man is fitted, by his conscious and corporeal constitution, to develop and employ speech, but the employment of the faculty by the child demands a certain amount of preliminary initiation; primitive man, in his peculiar circumstances, was in this, as in other essential elements of his spiritual and material welfare, beneficently supplied with the necessary initiation by an immediate or Divine process or act. . . . Man has no control over speech; he is merely an unconscious agent in its changes and progress. The first actual addition made by man to his faculty of speech is his written language, which has been followed up by all those arrangements by which thought and knowledge are recorded and transmitted through space and time."

Professor Goodsir deals with the human skull and brain with admirable perspicacity and force. He says of the skull: "The cephalic axis (axis of the head) is a right line extending in the mesial plane, from the anterior margin of the occipital foramen, along the floor of the nose to the incisive openings, and prolonged to the cartilaginous extremity of the nose. . . . The assumption of a line which shall represent the axis of the cranium involves the idea of its being continuous with that of the spine. The axial line of the head is horizontal. In man alone does this line touch the posterior as well as the anterior margin of the foramen magnum.

"The cervico-cephalic angle is the angle made by the axis of the spine with the axis of the head. This angle does not exist in the fish and amphibian, in which the axis of the head and spine forms a continuous line. In reptiles, birds, and mammals, this angle is more or less marked, but in none of them does it reach a right angle. In the different mammals the angle varies with the species. In man alone is the cervico-cephalic angle a right angle. . . . The greater curvature of the human skull is the fundamental condition of that enormous additional space afforded for the human brain, and also for the relatively abundant space provided for the nasal, oral, and pharyngeal cavities. . . . The antero-posterior and transverse curvatures of the vault of the skull, as well as the curvatures of the fossæ on the floor of the cranial cavity, are anatomically conditioned by the surface curvatures of the respective lobes of the cerebrum and cerebellum. The mass and form of the entire brain is the condition which determines the volume and curvature of the several compartments of the cavity which contains it, while the required mass of the entire organ is the condition which determines the permanence of the primordial form of antero-posterior curvatures. . . . The additional space which is obtained in the human cranium, like the completed areas of the joints in the human limbs, is provided for additional structure and corresponding extension of functions. . . . We can, in the present phase of science, only recognise the masses added. Of the structure and function of those additional masses we know at present nothing, beyond the little which has been ascertained regarding the mechanism and actions of the organ generally.

"The anatomy of the masses of the brain is the mere rudiment of the subject—the actual anatomy of the brain is its internal mechanism. Till that mechanism has been ascertained in man and the animal, the question as to the human and animal brain cannot be solved, and ought not, therefore, to be discussed in a dogmatic tone. . . . I myself entertain the firm conviction that, as the human brain exhibits in its geometrical proportion and mass a great superiority over the brain of any animal, a superiority similar to that presented by the human bones, joints, muscles, and organs of sense, so, in like manner, it may even now be safely assumed that under that cloud of ignorance which

at present conceals its inner mechanism, there exists a structural and functional completeness which will be found to distinguish it from every other form of brain."

It will be seen from the foregoing quotations, that Professor Goodsir held very decided opinions as to the origin, history, and destiny of man. He separated him from the animals, and placed him on a pinnacle by himself, both as regards his bodily configuration and as regards his intellectual and moral attributes. He also made him out a spiritual and religious being, with a conscious principle which enabled him to recognise an outer or external world and an inner or personal world which centres in himself. He believed that man was a separate creation, and not an evolution; that he was from the first an exalted, intellectual being, and that the race of savages or so-called wild men are degraded, aberrant human types, who owe their degradation to their having chosen the evil in preference to the good, who have indulged in wrong-doing and suppressed their better natures which were their birthrights. The degradation is chiefly a mental and moral one; the physical man being scarcely affected. This view harmonises with the career of vice even in the most civilised communities of the present day. Professor Goodsir attributed to man an upward and a downward tendency: in other words, according to him man is a retrogressive, as well as a progressive animal. Certainly, as man exists on the earth at present, he is both. The progress of crime in civilised communities, and the savagery which obtains in certain aborigines, proclaim the retrogressive phase of man's character, and the exalted ideals and godlike achievements of civilised modern man announce his progressive phase.

This double view of man's character completely accords with what occurs in the organic kingdom as a whole, where, both in plants and animals, we have constant examples of progression and retrogression within limits: progression leading to life and continuity, retrogression to death and disappearance.

The progressive and retrogressive phases of man's character absolutely account for man as he at present exists on the earth. They account for man as an intellectual, moral, religious being, and also for him as a degraded, immoral, and irreligious being, whether considered as a waif of society, or as a savage inhabiting unreclaimed lands.

The retrogressive phase includes all wild people, wherever located. In this connection it should be stated that there is a well-marked tendency in the aborigines, as a class, to return to a state of civilisation, and that they laboriously and ungrudgingly toil upwards through the stone age, the copper and bronze ages, and on to the iron age.

Conversely, civilised man, if cut adrift from his fellows, degenerates in a surprisingly short space of time. Alexander Selkirk, the famous Scotch castaway, when rescued from his solitary island, which he had occupied for only a few years, had nearly lost the power of speech.

The evolutionists endeavour to found what they regard as a strong and unanswerable argument on the existence of degraded man. They say he is but a step removed from the anthropomorphous apes, and consequently his ancestors must be apes. This does not at all follow, as, from Professor Goodsir's point of view, such an argument is, at best, a mere example of special pleading. Some would go further and dub it a *petitio principii*, or begging of the question at issue.

Looking at the subject in its totality, and regarding man as an intellectual, moral, and religious being, I have no difficulty in giving Professor Goodsir my undivided support, with the following reservations. I do not see my way to separate man so entirely from the animals as he does. Neither can I recognise as a valid distinction between the animal and man, that the animal is simply conscious, man being conscious and self-conscious. I also take exception to the sharp line drawn between so-called instinct and reason.[1]

I believe that there are separate creations or *types*, and a gradual rise in the scale of being from the monad to the man; that there are distinct types arranged in an ascending, progressive series; that the types are isolated and distinct, and do not merge or run into each other—that is, the one is not manufactured out of the other; that there is continuity of plan structurally and functionally; that this applies to the nervous system and brain; and that intellect, mind, and morals are questions of degree rather than of kind.

I am disposed to regard creation as a progressive work, not confined to six days or to any stated period. In my opinion, the additions to, and differentiations in, plants and animals, which go on at the present day, are

[1] The following are Professor Goodsir's words: "The brute is conscious of external objects only, while man cannot detach his consciousness of external objects from his consciousness of self. The brute is merely conscious—man is self-conscious. . . . On the other hand, that peculiar principle in the constitution of man, which acts independently on his instincts, and in virtue of which he is conscious of self, capable of apprehending the objects around him as external to self, enabled to exert his corporeal and psychical powers in the accumulation and co-ordination of ideas and their signs; but, above all, capable of determining between right and wrong, of recognising his own immortality, and his dependence, as well as the dependence of all around him, on his and their Divine Creator, is an intelligence altogether different in kind from the instinctively co-ordinated intelligence of the brute." (Goodsir's "Anatomical Memoirs," vol. i., p. 316.)

The distinction drawn by Professor Goodsir between man and the brute is upheld by Mr. St. George Mivart, F.R.S., in the following passage: "Man being, as the mind of each man may tell him, an existence not only conscious, but conscious of his own consciousness; one not only acting on inference, but capable of analysing the *process* of inference; a creature not only capable of acting well or ill, but of understanding the ideas 'virtue' and 'moral obligation' with their correlatives, freedom of choice and responsibility—man being all this, it is at once obvious that the principal part of his being is his mental power." ("Man and Apes:" *Popular Science Review*, vol. xii., p. 262.)

as much creations as those recorded in the book of Genesis. Everything in nature is continuous and progressive, and all modifications and adaptations of original structures are creations in a way. There are what may be regarded as primary and secondary creations; the former being the creations of types, the latter modifications and adaptations thereof.

I am supported in my last contention by Professors Owen and Huxley. Professor Owen[1] writes: "Not being able to appreciate or conceive of the distinction between the psychical phenomena of a chimpanzee and of a Boschisman or of an Aztec, with arrested brain growth, as being of a nature so essential as to preclude a comparison between them, or as being other than a difference of degree, I cannot shut my eyes to the significance of that all-pervading similitude of structure—every tooth, every bone, strictly homologous—which makes the determination of the difference between *Homo* and *Pithecus* the anatomist's difficulty."

Professor Huxley[2] follows in a similar strain. He observes: "No absolute line of demarcation, wider than that between the animals which immediately succeed us in the scale, can be drawn between the animal world and ourselves, and I may add the expression of my belief that the attempt to draw a psychical distinction is equally futile, and that even the highest faculties of feeling and of intellect begin to germinate in lower forms of life. At the same time, no one is more strongly convinced than I am of the vastness of the gulf between civilised man and the brutes; or is more certain that whether *from* them or not, he is assuredly not *of* them. No one is less disposed to think lightly of the present dignity, or despairingly of the future hopes, of the only consciously intelligent denizen of this world."

It is a curious circumstance that Professor Goodsir, who was the founder of cellular pathology, and to whom Professor Virchow dedicated his great work on that subject, should have been followed, in his defence of man as an original creation, by that doughty champion of science. Of all those who have opposed the evolution of man from the apes, and evolution generally, no one has shown a more uncompromising and formidable front than Professor Virchow. Professor Haeckel, in his "Evolution of Man," states, not quite logically, that Virchow had not the necessary training to deal with such a subject. Haeckel, however, himself traces the origin of man to a cell, and, certainly, no man in his day and generation knew more about cells than did Virchow. Professor Haeckel treats similarly other opponents of his pet theory. In more than one instance, those who enthusiastically espoused evolution in their youth but who formally renounced it in maturer years are twitted with senile decay. Evolution can scarcely hope to gain by side thrusts. If it is a sound doctrine, it—like good wine—requires no bush. It is not a little remarkable that Professors Goodsir and Virchow—the two most noted discoverers in cellular *pathology*, and who devoted much of their time to cellular *physiology*—should have so strongly opposed the theory of evolution and the descent of man from the apes.

Apart from man's origin, the only thing which remains to be considered is man's fitness to occupy the position assigned him in the animal kingdom and in the world. Does he in his physical, mental, and moral nature reveal the design which adapts him perfectly to his surroundings, and makes him ruler of the earth and all it contains? I reply unhesitatingly in the affirmative. In no instance is the argument for design more strikingly exemplified than in civilised man. He is a very centre of design, physically, mentally, and morally. His erect position, perfect binocular vision, highly-developed sense organs, large brain, symmetrical body, fine limbs and perfect hands and feet, proclaim him the paragon of animals. In no other animal are the arms and hands absolutely free to carry out the behests of the will, and in none are they so perfectly adapted to perform every conceivable kind of work. The human hand is one of the most wonderful pieces of mechanism known. It bristles with design in its highly-sensitive integument, touch corpuscles, and labyrinth of sensory nerves; in its rich supply of arterial, capillary, and venous blood; in its numerous muscles and tendons; and in its large number of small bones, and complicated joints with their appropriate ligaments. Its movements are practically universal. There is scarcely anything the human hand cannot do. It can make a watch and wield a sledge-hammer; it can produce a needle and an anchor with equal facility. "The human hand is formed in absolute harmony with the conditions of human thought. It is an instrument expressly framed to act under it and for it. Psychologically considered, it is the principal channel through which we derive the means of framing our conceptions of the form of bodies. Towards this end, it co-operates with the eye, bringing to the aid of the latter the combined results of the sense of touch, highly developed on the fingers and palm, and of the muscular sense of the entire limb."[3]

Similar remarks are to be made of the human foot. It is a perfect organ for locomotion on the land. It is arched in two directions—antero-posteriorly, and laterally—it is highly elastic and springy, but very strong; it seizes and lets go the earth with equal ease; it cushions the body and prevents shock to the superincumbent parts

[1] "On the Characters, &c., of the Class Mammalia." (*Journal of the Proceedings of the Linnæan Society of London for* 1857.)
[2] "Man's Place in Nature and other Anthropological Essays." London, 1901.
[3] "Anatomical Memoirs of the late John Goodsir, F.R.S.," vol. i., p. 321.

in walking, running, and jumping; it is the basis of support for the trunk in the standing position, and levers the body forward according to mechanical laws when it is progressing. Its movements are as numerous and precise, in a way, as those of the hand. It can be trained to take the place of hands when they are wanting, and it is not an uncommon thing to see an armless and handless man using a fork and knife and feeding himself with his foot. Still more remarkable is it to see him employing his foot and toes in painting and copying pictures. This I have myself on several occasions witnessed in the great picture galleries of the Continent.

What is said of the hand and foot of man is true of all the other parts of his body. He has the most perfect skeleton and the most powerful and highly developed muscular system known (see Figs. 254 and 255, p. 1030). As an athlete and gymnast he can outstrip all other animals. I have seen him perform all the feats attributed to monkeys, and others which no monkey would attempt. He can swim, and do everything but fly. His movements are at once the most graceful and wonderful of all created beings.

The corporeal perfection of man is capped by his greatly differentiated sense organs, his highly developed nervous system, and his large, powerful brain. His senses of touching, tasting, smelling, hearing, and seeing connect him directly or indirectly with everything outside of himself. He sees much, very much, with the natural eye, but he sees more, much more, with what may be designated the artificial eyes of the microscope, the telescope, and the photographic camera. The microscope reveals to his astonished gaze the infinitely minute and infinitely near objects, the telescope the immeasurably great and incalculably remote ones, and the camera depicts and stereotypes them for his examination and study at suitable and convenient seasons. Similarly, the natural ear and voice have been supplemented by the telegraph, telephone, phonograph, microphone, and wireless telegraphy. The spoken word, or its symbol, can be transmitted through space and heard all over the earth. The telephone not only conveys the spoken message, but all the inflexions and special intonation of the speaker; the phonograph records and stores up for future generations the heart-stirring speeches of the orator, and the warbling, delicious music of the gifted prima donna; the microphone increases, intensifies, and emphasises both; and wireless telegraphy literally harnesses the atoms and makes them subservient to the will of man. All nature proclaims him master. He ploughs the ocean with his powerful steamers; he rushes along the dry places at incredible speed with his locomotives, his motors, and his bicycles. There is, practically, no limit to his activity.

He founds empires and states, and builds cities and villages, and these he rules by legal and other codes, so as to ensure their harmonious working: he cuts down forests, and drains and reclaims lands, and so produces a new climate: he digs deep into the bowels of the earth, and secures coal, iron, copper, and other mineral wealth: he excavates canals, and tunnels mountains, and creates a network of railways which at once follows and heralds civilisation. He builds steam, petrol, electric and other engines, and these he compels to do the major part of his manual labour. He draws upon all the forces of nature. He places a yoke on the waterfall and the river, and causes them to turn mills of various kinds, to generate electricity, and to perform all kinds of menial work. He uses the electricity when made, or stores it up until it is required; he constructs vast reservoirs, and he catches and confines water, which he employs in irrigation and in supplying his numerous cities and villages: he manures and tills the soil, and greatly increases its fertility: he lights his cities artificially with gas and electricity, and supplies them with water and food, often conveyed long distances. He places in them universities and seats of learning, which dispense all known learning. He erects printing presses, which record, in an available form, the histories of peoples and things, not only for the present generation but for unborn generations: he establishes all kinds of industries —building, iron and pottery making, machine construction, baking, brewing, carpentering, engineering, &c. All the sciences are his servants—physics, chemistry, botany, zoology, anatomy, physiology, geology, palæontology, astronomy, agriculture, mathematics, mensuration, engineering, ethics, &c.

He controls every department of ancient and modern learning, and there is nothing known, or which can be known, on which he does not promptly lay his hands and set his seal. He aims at, and has practically achieved, universality in his control of matter and force. His conquest of the earth is a reality and not a metaphor. All the plants of the field and all the animals, great and small, are under his control and at his mercy. Man knows no competitor unless those of his own race. It is for him to dictate to everything that lives.

An enumeration of man's activities and powers completely separates him from any form of ape, past or present. The earlier the ape and the more remote the period, the more hopeless the task of identifying him with the apes becomes. Unlimited modification and unlimited time are the strongholds of evolution, but the advocates of this doctrine have no right to assume either the one or the other. They take for granted what they are logically bound to prove. The onus of proof is on the shoulders of the evolutionists rather than the creationists. If they rest their cause on practically impossible premises, thoughtful men are bound not only to suspect but also to deny their conclusions. If the number and extent of the modifications cannot be grasped, and the time required to make them cannot be measured, the question is removed from the category of things about which the human mind can

reason. Evolution becomes largely a figment of the imagination, and the sooner science sees this the better the outlook for humanity. There is no need to deny man's animal nature, but it would be a grave mistake not to fully recognise his superior mental and moral attributes.

Granted that man is all that the creationists make him, the question has still to be put, Whence comes the truly overwhelming power possessed by him? That power is mainly traceable to his large and superlatively fine brain. There his power centres, as the lightning in the cloud. The brain by its sense organs touches, tastes, smells, hears, and sees practically everything in the Universe. It is that which connects man with everything that is, which gears and binds him to nature, which assigns him his place in nature, which enables him to vanquish nature, and which secures for him his permanent place as the highest of the animal types.

THE MUSCULAR AND OSSEOUS ARRANGEMENTS OF MAN, AS BEARING ON EXPRESSION, RESPIRATION, LOCOMOTION, THE ERECT POSITION, &c.

§ 289. The Muscular and Osseous Systems of Man Interdependent and Complemental.

The muscular and osseous systems of man and the higher animals are necessary to each other. The skeleton supplies the solid framework for the support of the muscles, and likewise the levers and joints which the muscles actuate or set in motion in all bodily movements, whether in the body itself or outside the body, as in locomotion.

The muscles are the prime movers of the body, and the bones with their joints are, strictly speaking, only accessories or auxiliaries thereof. This being so, it is not necessary for me to take up the skeleton or osseous system in any great detail. It will suffice if I indicate, in a general way, its peculiarities.

The skeleton in man not only provides support and leverage for the muscles, it also furnishes protecting cavities for delicate and most important structures. Thus the skull protects the brain, the eyes, the ears, and the organs of sense; the spinal column protects the spinal cord; the bones of the thorax, abdomen, and pelvis protect the heart, lungs, liver, kidneys, alimentary canal, and glands.

The skeleton also, in virtue of its elasticity, and from its articulate surfaces being covered with cartilages or gristle, and from intervertebral cartilages or buffers being interposed between every two bones in the spinal column, receives, diffuses, and transmits shocks, which, under ordinary circumstances, would prove injurious. This power of diffusing and transmitting shocks is greatly increased by all the bones of the body, especially the long bones, being bent or arched, and twisted upon themselves screw-fashion. They are also invariably placed in the precise position and at the proper angles for receiving thrusts in all the bodily movements.

The skeleton, physically considered, is a perfect marvel of design. There are few principles in applied mathematics and mechanics which are not illustrated by it. The fulcrum, lever, wedge, screw, arch, tenon and mortice, pulley, universal hinge, and other joints, are all represented.

The bones, whatever their shape, are constructed on the best models for strength and lightness; the long bones being hollow cylinders filled with exquisite cancellous tissue arranged in a series of delicate curves and arches, which enormously contribute to their strength without adding almost anything to their weight. Certain bones are buttressed and strengthened by ridges and processes after the most approved mechanical principles; others develop rounded cavities to receive and retain by ligaments and atmospheric pressure the rounded heads of long bones endowed with universality of movement, such as those of the arm and thigh bones.

The joints formed by the several kinds of bones are numerous and cunningly devised. Some joints only permit of gliding movements within very narrow limits; others, such as the ginglymoid or hinge joints, admit of extensive movements confined to one plane; others are spiral in their nature, their movements not being confined to one plane; others are ball and socket or universal joints which can move in every direction. The joints are always covered with smooth cartilages and lubricated with synovial fluid to secure easy working, and to keep down friction. They are also provided with strong ligaments variously arranged, to limit their movements and to prevent accidental dislocation.

The skeleton is composed of animal matter and bone earth (phosphate and carbonate of lime); the former predominating *in utero* and in the young individual, where the bones are tough, highly elastic, and not easily broken. In old people, the bone earth predominates, and hence their bones are readily broken, especially as the angles formed by the necks of the long bones in advanced age are rendered less oblique, and are consequently less able to receive, withstand, and transmit shock. The bones of the head are soft, and yield and overlap in parturition, and by reducing the size of the head facilitate that difficult operation.

All the bones of the body are designed to receive, diffuse, and transmit shock either from above downwards, or from below upwards. The spinal column, as the centre or axis of the skeleton, is the best adapted to this purpose. It is composed of a numerous series of short, oval-shaped bones with processes and spines for the attachment of muscles—every two bones having a buffer of smooth cartilage placed between them, and being kept in position by ligaments which only admit of very limited motion—the spinal column as a whole having a considerable range of motion, and being thrown into four antero-posterior curves; the curves reversing and alternating, figure-of-8 fashion. Incipient lateral curves can also be traced. The spinal column is so constructed that it is at once strong and elastic, and can practically be moved in every direction, namely, forwards, backwards, to right, to left, and to any intermediate point. It can also be made to rotate in the direction of its length, and to twist spirally, if need be. In the spinal column are found all the movements which occur in the arms and legs in locomotion. In the serpent in crawling and the fish in swimming, the movements of the spinal column are seen to perfection. It provides the type for every form of bodily movement. The extremities of man and animals originally appear as buds or outgrowths from the trunk of which the spinal column is the centre. When they grow and mature, they assume, as was to be expected, the movements of the central axis of the trunk of which they are, in a sense, extensions.

All the bones of the body are arranged with a view to maintaining the erect position.

The skeleton in adult man consists of no fewer than 206 bones, excluding the sesamoid and wormian bones, and the teeth; namely, the cranium eight, the ossicula auditus six, the face fourteen, the vertebral column (including the sacrum and coccyx) twenty-six, the os hyoides, sternum, and ribs twenty-six, the upper extremities sixty-four, and the lower extremities sixty-two.

The spinal column consists of twenty-four true vertebræ (seven cervical, twelve dorsal, and five lumbar), and nine false vertebræ (five sacral and four coccygeal).

The ribs on either side consist of ten true and two false ribs.

The os innominatum, pelvis, or hip bone, is originally made up of six pieces; two iliac portions, two ischial portions, and two pubic portions.

The arm or anterior upper extremity, with its shoulder-girdle, is composed of the scapula, clavicle, humerus, radius, and ulna, the carpal and metacarpal bones, and the digits or fingers. It is articulated to the body by the shoulder joint, which is ball and socket or universal, and permits of movement in every direction.

The leg or posterior lower extremity consists of that portion of the pelvic bone containing the acetabular cavity, the femur, the tibia and fibula, the tarsal and metatarsal bones, and the phalanges or toes. It is articulated to the body by the hip joint, which, like the shoulder joint, is ball and socket or universal, and permits every kind of movement.

The bones are variously shaped, some being flat or curved and presenting a square appearance; others cube-shaped; others angular with ridges and prominences; others short, round, and oval with processes and spines; others of moderate length, and bent; others long, cylindrical, and curved.

The majority of the bones are more or less spiral, singly or in combination. The clavicles display double or S curves, and are twisted in the direction of their length. The ribs, one and all, are curved and twisted. The scapulæ are also twisted and spiral, and the same is true of the pelvic bones.

The bones of the arms and legs are markedly spiral, and the origins and insertions of the muscles of the arms and legs are, in many cases, confined to spiral lines on the surfaces of the bones in question. The spirality extends to the bones of the hands and feet, and to the muscles connected therewith. The joints are largely spiral.

The spirality is well seen in the limbs of the elephant.

That all the bones in question present spiral outlines is proved beyond doubt by a reference to the accompanying plate, where the figures have been delineated with extreme accuracy and according to scale, from specimens in my private collection (Plate cl.).

PLATE CL

Plate cl. illustrates the spiral configuration of the bones of the superior or anterior limbs of man and the elephant, and of the inferior or posterior limbs of man; also the spiral nature of the human clavicle, scapula, and pelvis.

FIG. 1.—Shows the spiral configuration of the bones forming the right superior extremity of man.

A. The humerus or arm bone. The darts *a*, *b* and *c*, *d* show that the bone is twisted upon itself; the spiral ridges running diagonally round the shaft. The same peculiarities are seen at B. The darts *e*, *f* and *g*, *h* of A show the spiral crossing of the ulna and radius as witnessed in pronation of the right hand. Pronation is virtually a rotatory movement of the bones of the hand and

PLATE CL

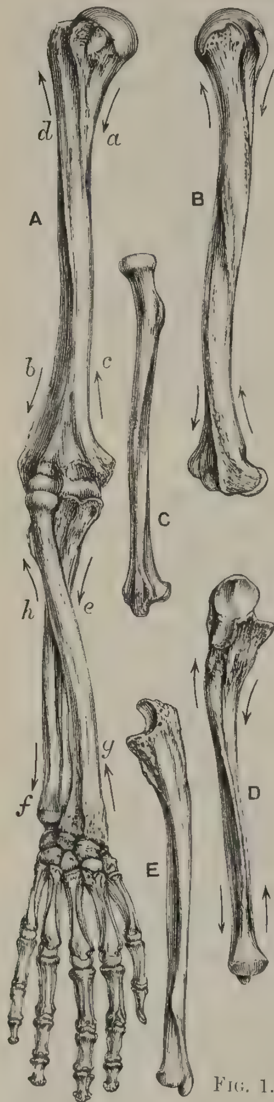


Fig. 1.

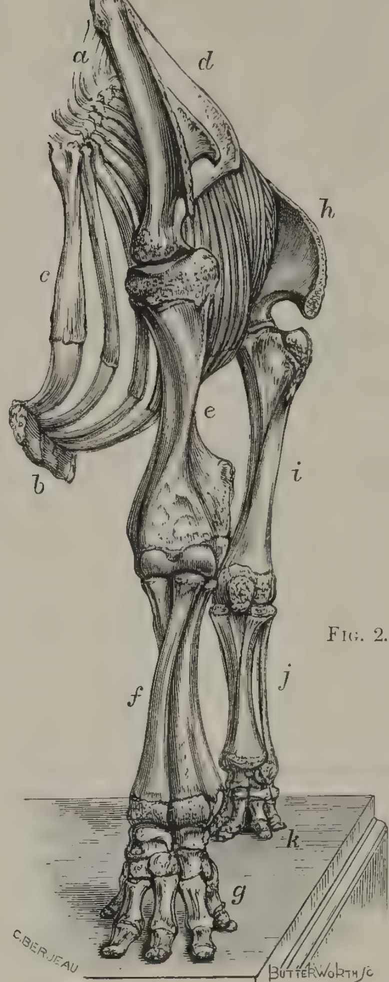


Fig. 2.

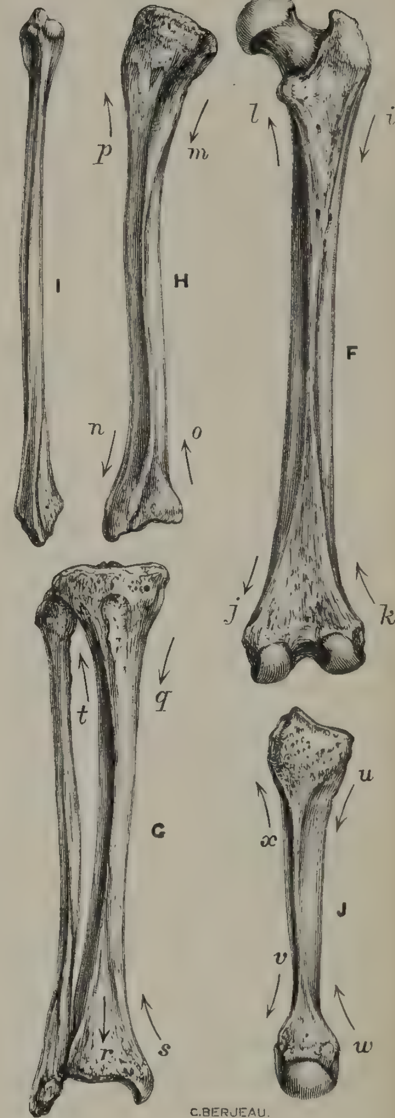


Fig. 3.

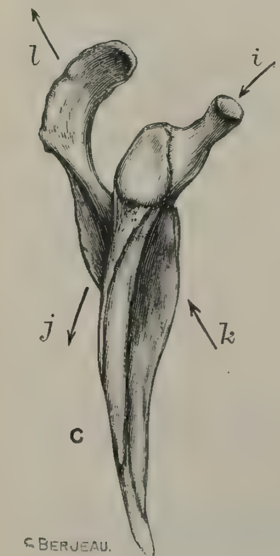


Fig. 4.

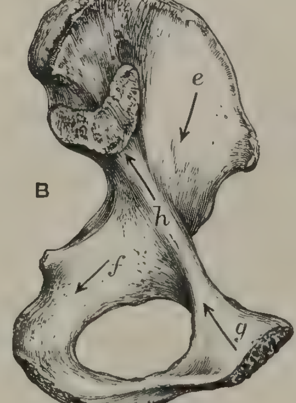


Fig. 6.

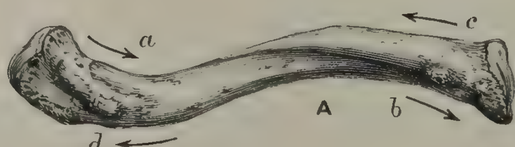


Fig. 7.

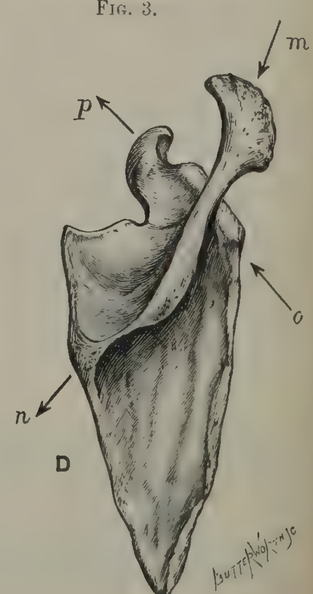


Fig. 5.

PLATE CL (*continued*)

radius in the direction of the length of the arm. Pronation and supination of the hand are screwing movements, and may be compared to those of a screw-nail, gimlet, and auger when these instruments are screwed and unscrewed in wood. The pronating and supinating movements, and the movements of circumduction occurring at the right shoulder joint, produce a rotatory movement of the arm in the direction of its length. These movements are the outcome of the spiral configuration of the bones, joints, and muscles of the arm, and compel the arm to move in spiral curves in walking and running, as they swing backwards and forwards pendulum fashion.

C. Shows the spiral configuration of the radius.

D. and E. Show the spiral configuration of the ulna.

Drawn according to scale for the present work by C. Berjeau from bones in the Author's private museum.

Fig. 2.—Portion of the skeleton of an elephant, showing that the bones of the scapula, pelvis, and anterior and posterior extremities are twisted upon themselves and form spiral structures. *a*, Spinal column ; *b*, sternum ; *c*, ribs ; *d*, scapula.

Left anterior extremity. *e*, Humerus ; *f*, radius and ulna ; *g*, phalanges.

Left posterior extremity. *h*, Pelvic bone ; *i*, femur ; *j*, tibia and fibula ; *k*, phalanges.

The screw configuration of the bones is well seen at *e*, *f* and *i*, *j*. If the left anterior extremity with the left scapula to which it is attached be carefully examined, it will be seen that the spiral lines forming the ridges of the screws run alternately from before backwards and downwards, and from before backwards and upwards. The same is true of the bones forming the scapula and pelvis, and the anterior and posterior extremities of man (Figs. 2, 3, and 4 of this Plate).

The spiral construction of the bones and joints, and the arrangement of the muscles in the extremities of the elephant, show very conclusively that the limbs of the animal when walking and running of necessity describe double-curve or figure-of-8 trajectories. What is said of the limbs of the elephant holds good of those of quadrupeds as a whole, and also of bipeds.

From a photograph, specially taken for the Author for the present work, of the skeleton of the famous elephant, Chuny, preserved in the Royal College of Surgeons of England, London.

Fig. 3.—Illustrates the spiral configuration of the bones forming the right inferior extremity of man.

F. Femur or thigh bone. The darts *i*, *j* and *k*, *l* show the spiral ridges so well seen at A (humerus or arm bone).

G. Leg bones—tibia and fibula. The darts *q*, *r* and *s*, *t* show the diagonal spiral ridges of the tibia.

H. Another view of the tibia showing the same thing (see darts *m*, *n*, and *o*, *p*).

I. Displays the spiral ridges in the fibula.

J. Reveals the same peculiarities in one of the metatarsal bones greatly enlarged (*vide* darts *u*, *v* and *w*, *x*).

Drawn according to scale for the present work by C. Berjeau from bones in the Author's private museum.

Figs. 4, 5, 6 and 7 (A, B, C, D).—Show how the human clavicle, pelvis, and scapula are twisted upon themselves.

A. Illustrates the spiral nature of the clavicle (collar bone). The darts *a*, *b* and *c*, *d* indicate the direction of the twisting.

B. Reveals the twisted spiral nature of the human pelvic or hip bone (*vide* darts *e*, *f* and *g*, *h*).

C. Shows the twisted spiral nature of the human scapula or shoulder bone as seen from before (see darts *i*, *j* and *k*, *l*).

D. The same as seen from behind (*vide* darts *m*, *n* and *o*, *p*).

Drawn according to scale for the present work by C. Berjeau from bones in the Author's private museum.

The spirality so conspicuous in the bones of the body extends also to the joints. These, with few exceptions, are likewise spiral. The elbow and knee joints, although usually regarded as simple hinge joints, are, strictly speaking, spiral in their nature.

The skeleton and its joints consist of a congeries of curves and spirals which can always be found if sought for. The muscles attached to the bones, which act upon the joints, are also for the most part spirally arranged either as regards their origins and insertions or their directions. The spiral factor in the bones, joints, and muscles is necessary for the production of the alternating, overlapping, continuous spiral movements witnessed in locomotion.

Speaking generally, it may truly be affirmed that the osseous and muscular systems of man and animals are composed of an aggregation of curved and spiral structures which are mutually adapted to each other, and which produce those graceful movements we so much admire in man and in the higher animals, such as the horse, deer, &c.

It is not necessary at this stage to discuss at greater length the peculiarities of the osseous and muscular systems. This is done in other parts of the work. I will therefore content myself by submitting fine views of the human skeleton as seen from before, and of the skeletal muscles of man as seen from before, laterally, and from behind. These views cannot fail strongly to impress the reader, as they reveal a complex and powerful combination of bone and muscle which has a First Cause and design stamped on every part (Figs. 254 and 255).

§ 290. The Muscular Arrangements of Man as a Whole.

In bipeds and quadrupeds the muscles are usually divided into voluntary, involuntary, and mixed, according as they are controlled by the will, partly so, or not at all. The muscles of the limbs afford examples of voluntary muscles ; those of the heart, stomach, uterus, and diaphragm of involuntary muscles ; and those of the gullet of mixed muscles. Habit and repetition, long continued, practically convert voluntary into involuntary muscles, as is well exemplified in the movements of walking, running, swimming, and flying. Muscles are, for the most part,

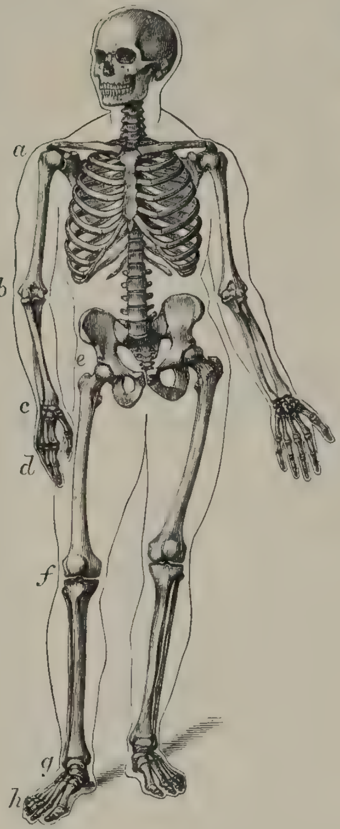


FIG. 254.

FIG. 255.

FIG. 254.—Human skeleton, seen anteriorly. *a*, *b*, Humerus or arm bone with shoulder joint (*a*) and elbow joint (*b*); *b*, *c*, radius and ulna forming forearm with wrist joint (*c*); *c*, *d*, carpal, metacarpal, and finger bones with corresponding joints of hand; *e*, *f*, femur or thigh bone with hip joint (*e*) and knee joint (*f*); *f*, *g*, tibia and fibula with ankle joint (*g*); *g*, *h*, tarsal, metatarsal, and toe bones with corresponding joints of foot (the Author).

FIG. 255.—Muscular system of man as seen anteriorly, laterally, and posteriorly.

The anterior view (left figure) reveals the muscles of the face, neck, chest, abdomen, arms, and legs. The muscles on the anterior aspect of the body, it will be observed, run in every direction—vertically, slightly obliquely, obliquely, and transversely. The arrangement of the muscles of the face, thorax, abdomen, legs and arms is very striking—especially the great pectoral, deltoid, and rectus abdominus muscles and the muscles of the forearms and thigh. A study of these muscles shows how the spiral, rotatory, and circumductory movements of the arms and legs are produced. The deeper muscles of the parts named emphasise the movements in question.

The lateral view (middle figure) shows the muscles on the right side of the body, face, and neck, especially the deltoid, or shoulder muscle, the biceps, triceps, great pectoral, latissimus dorsi, costal, external oblique, and gluteal or hip muscles; also the muscles on the outer and inner sides of the thighs and legs.

The muscles on the shoulders and arms show how the arm is elevated and flexed, and how it may be lowered and extended. Those on the buttocks and legs show how the leg may be flexed and extended, and how circumductory, rotatory, and spiral movements may be communicated to it. These movements are increased by the action of the deeper muscles of the arms and legs.

The posterior view (right figure) displays the beautiful symmetry of the muscular system. It shows the muscles of the back part of the head and neck, and especially of the back of the trunk, arms, and legs. It displays the great fan-shaped muscles of the back, namely, the trapezius and latissimus dorsi muscles, with certain of the scapulæ muscles, the deltoid or shoulder muscle, the biceps and triceps muscles of the arm, and the muscles of the forearm. It also shows the great glutei or hip muscles, the ham-string muscles of the thigh, and the powerful gastrocnemius muscles forming the calves of the legs. The superficial muscles of the back of the body, arms, and legs are supplemented by deep muscles which contribute to the flexion and extension and rotatory, spiral movements of the spinal column and limbs (after Leveillé, as explained by the Author).

arranged spirally in vertical, slightly oblique, oblique, and transverse lines, which cross or tend to cross each other at various angles. Thus the vertical muscles, which I usually designate straight muscles, cross or tend to cross the transverse ones at right angles; the oblique muscles crossing at wider angles as their obliquity increases. The fibres in these muscles are variously distributed, some running parallel, some radiating to form fan-shaped muscles;

others springing from a raphe or midrib and producing penniform muscles. The shape of the muscles is in part determined by the arrangement of their fibres. Muscles are conveniently classed as long, short, triangular, and quadrate. They are sometimes twisted and plicate, and sometimes circular. The long muscles are generally rounded, bellied, and spindle-shaped; the short, triangular and quadrate muscles being, in the majority of cases, flattened. The muscles are, as a rule, provided with tendons by which they arise from one bone and are inserted into another by what are known as origins and insertions. These origins and insertions are frequently spiral in their nature. The muscles move the bones—the osseous system being, in reality, an auxiliary of the muscular system. The muscles not unfrequently in part arise from fasciæ; the fasciæ consisting of sheets of strong fibrous tissue which maintain the shape of the body and of the muscles as a whole. They also arise from aponeuroses. The muscles seldom or never act singly. On the contrary, they are arranged in groups, and act together. Perhaps the best example of simple muscles, arranged in pairs, is afforded by the recti (superior, inferior, external, and internal) of the eyeball (Fig. 256).

Muscles act in nearly straight lines and at every degree of obliquity; they even act at right angles or round the corner by the aid of pulleys and grooves as in the superior oblique muscles of the eyeballs, and the digastric muscles of the neck. Occasionally, the tendons of muscles are retained in position by transverse fibrous bands, as in the so-called annular ligaments which occur at the wrist and ankle joints. In such cases the movements of the tendons are confined within prescribed limits.

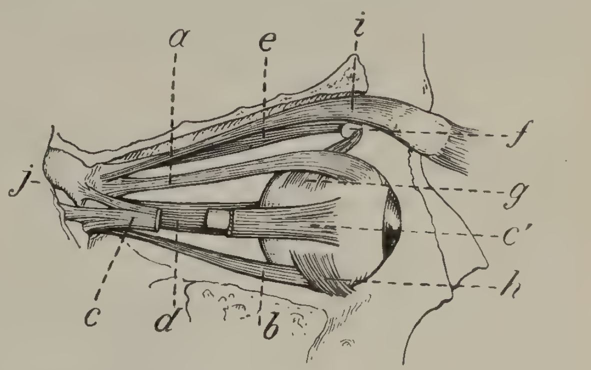


FIG. 256.

FIG. 256.—Muscles of the right eyeball. Shows how the eyeball can be made to move upwards, downwards, outwards, and inwards, and how it can be made to rotate upon its axis. *a*, Superior rectus muscle; *b*, inferior rectus muscle; *c*, *c'*, external rectus muscle cut across; *d*, internal rectus muscle. These four muscles act in pairs. When the superior rectus contracts or shortens, the inferior rectus relaxes or elongates, with the result that the eyeball is pulled upwards. When the inferior rectus muscle contracts or shortens, the superior rectus relaxes or elongates, and the eyeball is pulled downwards. The recti can combine to produce diagonal movements of the eyeball, in which case it is made to move upwards and inwards, upwards and outwards, downwards and inwards, or downwards and outwards. The same thing happens in the external and internal rectus muscles when the eyeball is pulled outwards or inwards. The rotation of the eyeball on its axis is produced by the superior oblique muscle (*e*), which works round the corner by means of a pulley (*f*). The superior and inferior oblique muscles (*g*, *h*) cause the eyeball to rotate at pleasure. The superior oblique acting alone rotates the globe so as to carry the pupil outwards and downwards to the lower and outer side of the orbit; the inferior oblique rotating the globe in such a direction as to carry the pupil upwards and outwards to the upper and outer angle of the eye. *i*, Levator palpebræ superior; *j*, sphenoid bone (after Gray).

The so-called straight muscles have, as explained, a slight degree of spirality in them, and act on hinge joints such as the elbow joint. Strictly speaking, the elbow joint is not a simple hinge joint but a very attenuated, *spiral* hinge joint. The knee joint, which is the homologue of the elbow joint, is, as Professor Goodsir showed, distinctly spiral in its nature. As a matter of fact, nearly all joints are more or less spiral, singly or in combination. This is true of the vertebral column, of the wrist and ankle joints, and of the carpal and metacarpal, tarsal and metatarsal, and phalangeal joints; these being formed by a large number of small bones. The greater or less degree of spirality in the so-called straight muscles and hinge joints is necessitated by the existence in the bodies of men and animals of a large number of slightly oblique, oblique, and transverse muscles. As the straight muscles, in not a few cases, act in concert with the slightly oblique, oblique, and transverse muscles, so the hinge joints act in concert with the ball and socket or universal joints. In locomotion, all or nearly all the muscles of the trunk and extremities are moving simultaneously, and the same is true of the joints. The muscular movements and the movements of the joints naturally and necessarily run into each other.

The rule is, that the straight muscles on one side or aspect of a limb flex, fold, and shorten the limb, and the straight muscles on the opposite side or aspect extend, straighten, and elongate the limb; it being reserved for the oblique and transverse muscles to rotate, circumduct, pronate, and supinate the limb. The alternate shortening and lengthening of a limb, and its rotation and circumduction in two opposite directions, are cardinal points in the locomotion of all the higher vertebrates, whether bipeds or quadrupeds. Without the shortening and elongating and the rotatory circumduction movements referred to, the diagonal twisting and screwing movements which, as I demonstrated in 1867,[1] occur at the shoulders and hips, and in the limbs themselves, in the walking and running of bipeds and quadrupeds, would be impossible. Similar remarks apply to the swimming of mammals, birds, and fishes, and the flying of birds and bats.

The trunk and limbs in locomotion develop double curves or figure-of-8 trajectories, as I fully explained at the date in question (1867).

[1] "On the Mechanical Appliances by which Flight is Attained in the Animal Kingdom." (*Trans. Linn. Soc.*, vol. xxvi.)

In order to realise what is here stated, it is necessary to examine the muscular system more or less in detail.

The general arrangement of the superficial muscles of man and of the horse is given at Fig. 255, p. 1030, and Fig. 347, p. 1098.

These figures convey a large amount of interesting and valuable information. It is necessary, however, to examine the deep muscles also, and I propose briefly to describe in this place, the muscles occurring in the face, neck, trunk, and limbs of man in so far as they bear on expression, respiration, locomotion, and the erect position.

The muscular system of man fitly represents that of all the higher vertebrates, and is avowedly the most perfect. I am indebted for many of the illustrations of this part of the work to the excellent volume "Anatomy, Descriptive and Surgical," by Mr. Henry Gray, F.R.S. The descriptions, as a rule, express my own views, and for these I am alone responsible.

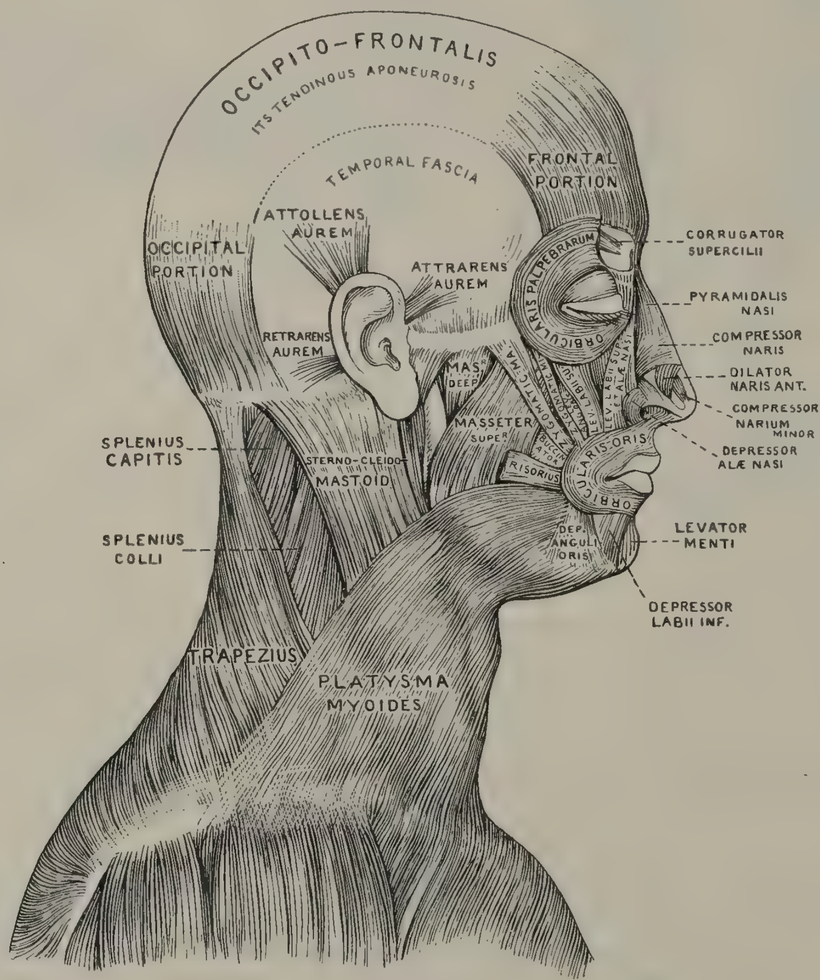


Fig. 257.

§ 291. The Muscles of the Head, Face, and Neck (Human).

The muscles of the human face are numerous and varied, and run in every direction, in nearly straight lines, obliquely, transversely, and in circles (Fig. 257).

The face reveals a veritable storehouse of muscles and muscular arrangements, nor will this occasion surprise, considering the extraordinary power of movement and expression which this part of the frame exhibits. In no region of the body are the muscles more numerous and complicated. Each part has its own peculiar muscles—the ear, the eye, the nose, the cheeks, the chin, and the jaws. These muscles act singly and in combination to produce the literally kaleidoscopic effects witnessed in an expressive human countenance. If to the movements

of the facial muscles be added the expression and movements of the eyes, a bewildering array of light and shade resembling that seen in the flickering borealis rivets the attention. The aural muscles move the ears, and, in the case of animals, turn them in the direction of sounding bodies; the frontal muscles smooth or corrugate the brow; the orbicular and palpebral muscles close or partly close and open the eyes; the recti and oblique muscles of the eyes move them in every direction, and confer a veritable wealth of expression which is greatly enhanced by the contraction and dilatation of the iris or coloured part of the eyes, or, what is the same thing, the diminution and increase of the apertures of the eyes known as the pupils. The intrinsic muscles of the nose cause the nostrils to dilate and expand, as in sniffing odours and in nervous excitement, or to contract, as in cold or fear; the oral muscles confer on the mouth and lips an infinity of movement and expression—these muscles consisting of a prominent circular muscle with muscular slips radiating upwards, downwards, and laterally. The circular muscle with its muscular slips can pucker and close, and dilate and open the mouth; the superior and inferior muscular slips having power to elevate the upper lip and to depress the lower one, and the lateral ones to raise the angles of the mouth as in joy, or to depress them as in grief. The muscles of the jaw take part in opening and closing the mouth—their chief function being to move the lower jaw, which, employing the fixed upper jaw as an abutment, chews or masticates the food.

The muscles of the face are remarkable in this, that they take the prevailing bent of the mind as a tree on a hill-top takes that of the wind. This is readily explained. The facial muscles in the child and young individual are highly plastic and mobile, and as the mind develops, firms up, and takes form, the muscles, which are its satellites and exponents, receive its characteristic expression as the fluid wax receives the impress of the seal. In this way the prevailing tenor of the mind becomes stereotyped and fixed in the face and eyes. Thus if the mind be naturally buoyant and gay, the eyes sparkle, and the mouth assumes a pleasant, smiling expression. If the mind be moody and dissatisfied, the eyes are lustreless and the corners of the mouth turned down. If the mind be stern and resolved, the lips are compressed and the mouth more or less pursed.[1] Between the three phases of mind indicated, numerous others might be noted, but into these I need not enter.

The muscles of the face are conveniently enumerated from above downwards (Fig. 257)—their names for the most part indicating their function. They are as follows: frontal portion of the occipito-frontalis, corrugator supercilii, orbicularis palpebrarum, pyramidalis nasi, compressor naris, dilator naris anterior and posterior, compressor narium minor, depressor alæ nasi, orbicularis oris, levator labii superioris et alæ nasi, levator labii superioris, levator angulæ oris, zygomatic major and minor, masseter (superficial portion), risorius, depressor angulæ iris, depressor labii inferior, and levator menti.

The muscles of the head and neck are less numerous and complicated than those of the face. The chief muscles of the head are the occipito-frontalis (frontal and occipital portions), the ear muscles (attollens aurem, attrahens aurem, and retrahens aurem), with the powerful temporal muscles, and masseters. These muscles are quadrilateral and fan-shaped, and consist of straight fibres following the curved contour of the skull, and of radiating fibres which spread forwards, upwards, and backwards.

The muscles of the neck run in nearly straight lines, obliquely and transversely. The superficial muscles (platysma myoides, trapezius and sterno-cleido-mastoid) cross each other obliquely; the deeper muscles running in a slightly oblique direction, some of them (digastric, stylo-hyoid, and posterior belly of hyoid) running in a nearly transverse direction.

The muscles of the head, face, and neck give an epitome of the muscles of the trunk and extremities; these running in straight lines with an element of spirality, slightly obliquely, obliquely, and transversely. In the trunk and limbs the directions indicated can always be made out.

The arrangement of the voluntary muscles closely resembles that met with in the involuntary muscles as seen in the ventricles of the heart of the mammal, and the stomach, bladder, uterus, and diaphragm.

Examples of the voluntary, involuntary, and mixed muscles occur in the tongue, pharynx, and soft palate, and are shown at Figs. 258, 259, and 260. They foreshadow the general muscular arrangements.

§ 292. Muscles and Bones of the Trunk—Thorax and Abdomen (Human).

Before describing the muscles of the thorax and abdomen it is necessary to give illustrations of such parts of the skeleton as enter into the formation of the thoracic and abdominal cavities respectively. I therefore submit views of the bones of the chest, pelvis, and shoulder girdle (Figs. 261, 263, and 264).

[1] As bearing out what is here stated, it may be mentioned that people who have married young acquire, in many cases, the same facial expression notwithstanding great original diversity of feature. The resemblance is due to thinking alike, and to common aims in daily life.

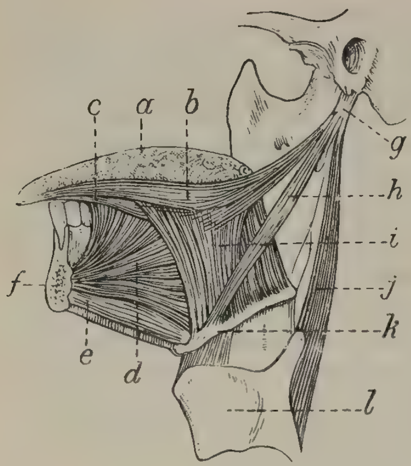


FIG. 258.

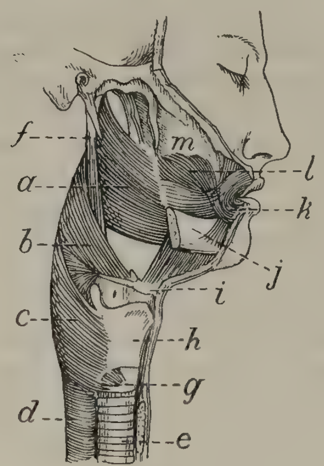


FIG. 259.

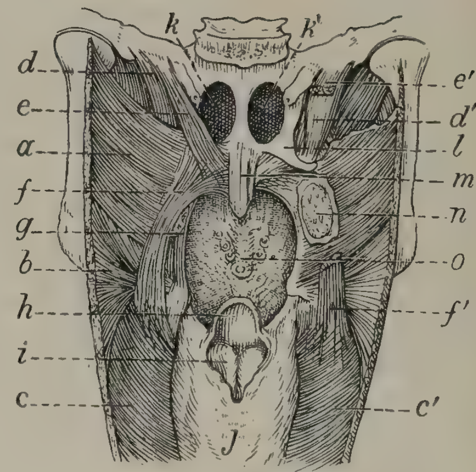


FIG. 260.

FIG. 258.—Muscles of the tongue. *a*, Dorsum of tongue; *b*, stylo-glossus; *c*, lingualis; *d*, genio-hyo-glossus; *e*, genio-hyoid; *f*, symphysis; *g*, styloid process; *h*, stylo-hyoid; *i*, hyo-glossus; *j*, stylo-pharyngeus; *k*, hyoid bone; *l*, thyroid cartilage.

FIG. 259.—Muscles of the pharynx. *a*, Superior constrictor; *b*, middle constrictor; *c*, inferior constrictor; *d*, œsophagus; *e*, thyroid gland; *f*, stylo-pharyngeus; *g*, cricoid cartilage; *h*, thyroid cartilage; *i*, hyoid bone; *j*, lower jaw; *k*, orbicularis oris; *l*, buccinator; *m*, upper jaw.

FIG. 260.—Muscles of the soft palate. *a*, Superior constrictor; *b*, middle constrictor; *c*, inferior constrictor; *d*, *d'*, tensor palati; *e*, *e'*, levator palati; *f*, palato-pharyngeus; *g*, palato-glossus; *h*, epiglottis; *i*, larynx; *j*, œsophagus; *k*, *k'*, posterior nares; *l*, hamular process; *m*, azygos uvulæ; *n*, tonsil; *o*, dorsum of tongue.

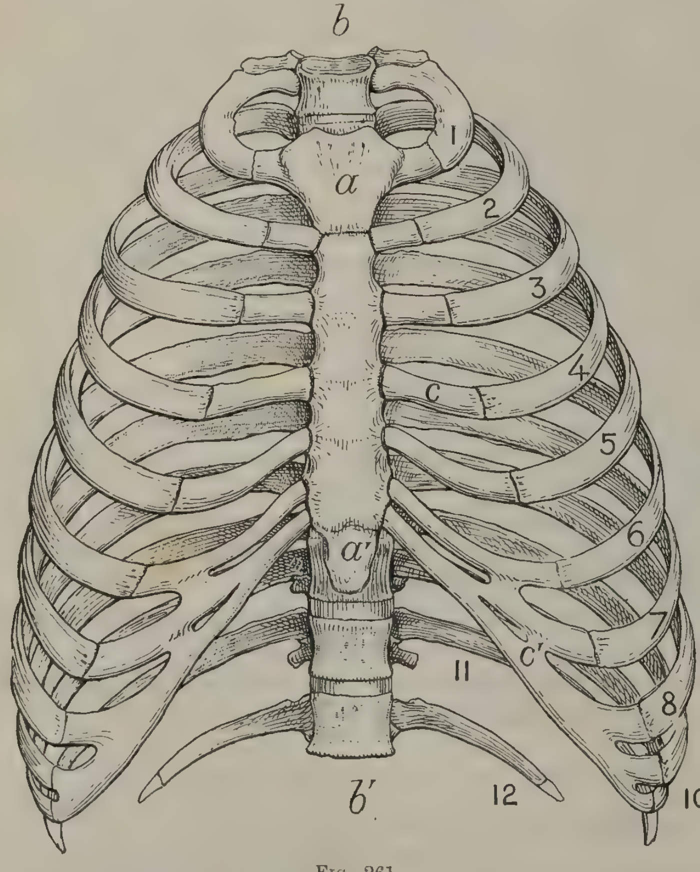


FIG. 261.

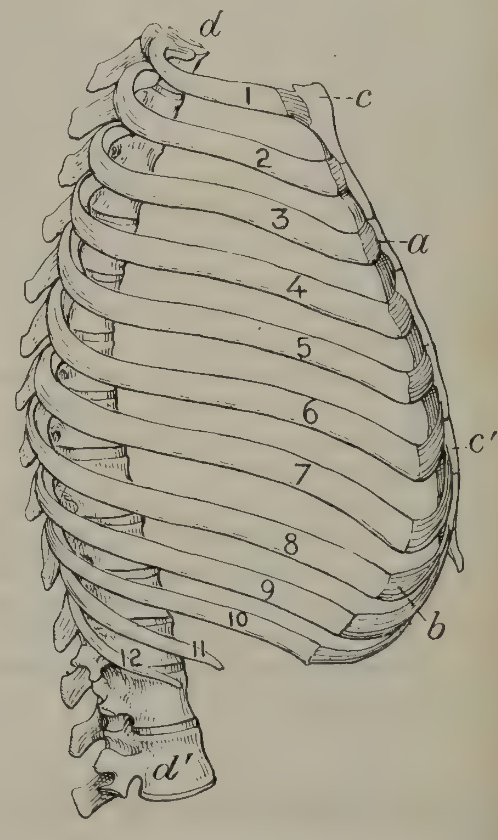


FIG. 262.

FIG. 261.—*a*, *a'*, The sternum or breast bone; *b*, *b'*, the vertebral column or back bone; *c*, *c'*, the cartilages of the ribs. The numerals 1 to 12 indicate the ribs (after Holden).

FIG. 262.—Lateral view of the human thorax and upper part of abdominal cavity, showing the back bone, the sternum or breast bone, and the ribs. The ribs are enumerated from above downwards—see numerals. *a*, *b*, Cartilages of ribs; *c*, *c'*, sternum; *d*, *d'*, vertebral column or back bone (after Holden).

§ 293. Anterior View of the Bones and Cartilages of the Human Chest.

The thoracic bones enclose a finely-rounded, somewhat flattened, dome-shaped cavity, and provide a framework of great strength for the protection of the lungs, heart, and other important viscera. The bones of the chest are intimately connected with the respiratory movements on which the aëration of the blood, within the chest, largely depends (Fig. 261).

§ 294. Lateral View of the Bones of the Human Chest.

The side view of the chest shows that the ribs are directed obliquely downwards and forwards, and are so articulated to the back bone that they can be readily elevated and depressed by muscular action.

Fig. 262 explains how the ribs, by the alternate contractions and elongations of the thoracic and abdominal muscles, can be rucked up and directed outwards during inspiration, when the cavity of the thorax is enlarged, and how they can be drawn down and inclined inwards when the cavity of the thorax is diminished, as in expiration. The diaphragm or muscular partition which separates the thorax from the abdomen plays an important part in the respiratory movements; it being arched upwards when the ribs are elevated, and flattened when the ribs are depressed. The opening and closing movements of the chest in respiration are largely vital in their nature, but the elasticity of the ribs also comes into play, although not to the extent usually believed.

§ 295. Bones of the Chest and Shoulder Girdles which take part in the Swinging-Pendulum-Movements of the Arms in Locomotion in Man.

Fig. 263.—Bones of the chest, including the back bone, breast bone, ribs, collar bones, shoulder blades, and upper portions of arm bones. *a*, Cervical portion of back bone or vertebral column; *b*, breast bone or sternum; *c*, *c'*, ribs; *d*, *d'*, collar bones or clavicles; *e*, *e'*, shoulder blades or scapulæ. The collar bones and shoulder blades form the shoulder girdles which receive and support the heads (*f*, *f'*) of the arm bones or humeri (*g*, *g'*). The heads of the humeri (*f*, *f'*) form ball and socket joints with the glenoid cavities of the scapulæ. The ball and socket joints permit the anterior extremities to swing backwards and forwards pendulum-fashion and to rotate and circumduct in the direction of their length in walking and running. They are thus enabled to form curves in two or more directions, and to take part in the formation of figure-of-8 trajectories in locomotion (the Author).

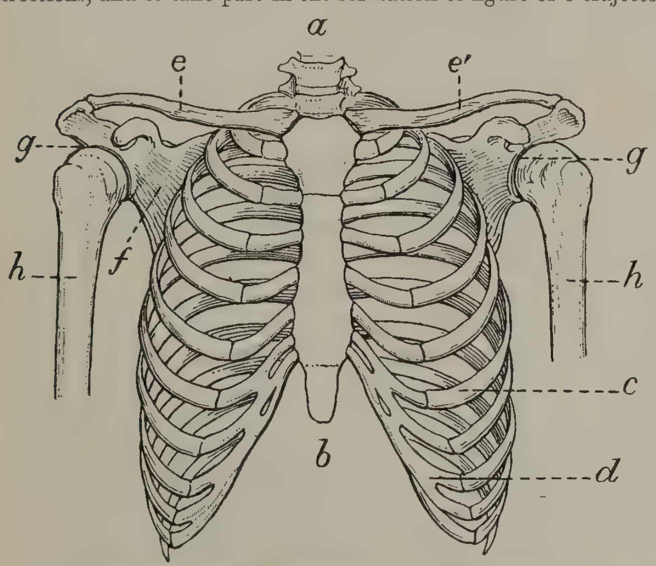


Fig. 263.

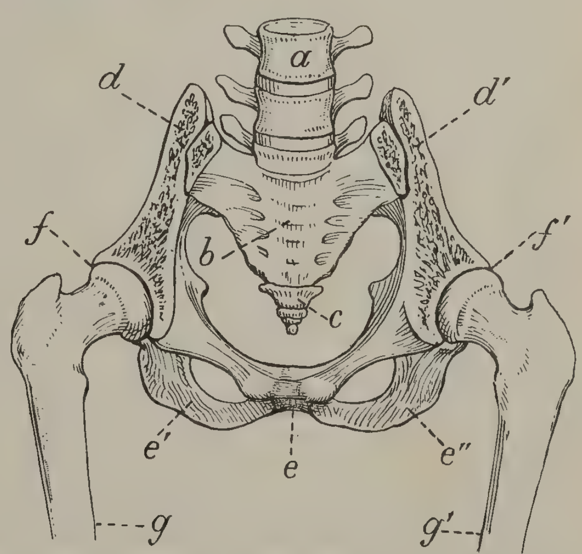


Fig. 264.

§ 296. Section of the Bones of the Human Pelvis, showing the Pelvic Arch, the Lower Portion of the Vertebral Column, and the Upper Parts of the Femurs or Thigh Bones with their Ball and Socket or Universal Joints engaged in the Pendulum-Movements of Walking, Running, &c.

Fig. 264.—*a*, Lower portion of vertebral column terminating in sacrum (*b*) and coccyx (*c*); *d*, *d'*, iliac bones cut across; *e*, symphysis pubis with its rami (*e'*, *e''*). The parts marked *a*, *b*, *c*, *d*, *d'*, *e'*, *e''* form the powerful pelvic arch which supports the vertebral column and everything attached to it. It is in turn supported by the heads (*f*, *f'*) and shafts (*g*, *g'*) of the femurs or thigh bones. The pelvic arch receives and transmits shocks both from above and below, and because of its great elasticity acts as a very perfect buffer. It safeguards walking, running, and jumping. This figure shows to advantage the fine ball and socket joints (*f*, *f'*) made by the heads of the femurs with the acetabular cavities of the pelvis, and how the legs can be swung in all directions pendulum-fashion. They can also be made to rotate in the direction of their length, and to circumduct when performing the various evolutions of which they are capable. They are thus enabled to form curves in two or more directions and to assist in the production of the figure-of-8 trajectories in locomotion as already indicated (after Holden; as explained by the Author).

§ 297. Muscular and other Arrangements of the Shoulder and Hip Joints in Man.

While the shoulder and hip joints are undoubtedly homologous structures, it is important to point out that they do not occupy exactly the same position with regard to the mesial plane of the body.

Thus the shoulder joint is directed outwards and forwards, while the hip joint is directed outwards and backwards. As a matter of fact, the shoulder joint is twisted forwards nearly a quarter of a turn. This is proved by the flexing of the arm and leg respectively. When the arm is flexed at the elbow joint, the forearm naturally occupies a position in front of or across the thorax; when the leg is flexed at the knee joint, the sole of the foot is pointed directly backwards, and occupies an antero-posterior position. The flexed arm and leg are arranged, as nearly as may be, at right angles to each other. The positions of the shoulder and hip joints are determined by the kind and amount of work to be performed by them. The shoulder joints, looking forwards, incline the arms in front of the body, where they are most useful for protection, and where they can perform an infinite variety of movement under the direct guidance of the eyes and brain; the hip joints, looking backwards, are mainly concerned in the antero-posterior movements of walking and running. When the arms are extended and swinging pendulum-fashion in space, as happens in walking and running, their movements are antero-posterior in character, and closely correspond with the movements of the legs. Under these circumstances, they take part in locomotion; the right arm and left leg advancing diagonally and simultaneously in curves to form one step—the left arm and right leg advancing diagonally and simultaneously in curves to form a second step. As the curves produced by the right arm and left leg form one half of a figure-of-8, and the curves produced by the left arm and right leg form the remaining or second half, it follows that a figure-of-8 trajectory is made by the arms and legs every two steps. The diagonal movements of the arms and legs are primarily connected with the shoulder and hip joints, and are of great importance in screwing the body forwards in walking and running by a swinging, alternating motion which gets the moving parts over their dead points, and insures a wonderfully perfect balance of the moving mass.

If the right arm and right leg were to advance simultaneously to form one step, and the left arm and left leg were to move simultaneously to form the second step, the right and left halves of the body would be advanced alternately by successive jerks as in the giraffe, and the diagonal, complemental, smooth-working balancing movements referred to would be destroyed. This would be a functional misfortune, as it would impair the efficiency of the diagonal, screwing, pendulum movements made by the arms and legs in walking and running, destroy the poise of the body, and completely obliterate the graceful deportment which characterises the locomotion of man and the great majority of bipeds and quadrupeds.

That the diagonal screwing movements to which I refer as occurring at the shoulders and arms and at the hip and legs are not imaginary, can be readily proved by a careful study of the walking and running of bipeds and quadrupeds from various positions, and by the aid of instantaneous photographs—a large number of which are given further on. The movements in question can readily be detected by the trained eye, and I direct special attention to them, as they supply the key to every kind of locomotion in the reptile, the bird, and the mammal.

When the right shoulder joint is screwing forward and causing the right arm to form a curve whose convexity is directed away from the right side of the body, the left hip joint is at the same time screwing forward and causing the left leg to form a curve whose convexity is directed away from the left side. These movements constitute one step. A second step is made by similar movements on the part of the left shoulder joint and left arm, and the right hip joint and right leg. The four opposite alternating curves made by the arms and legs produce the fundamental figure-of-8 trajectory which characterises the locomotion of bipeds and quadrupeds under all circumstances.

The importance of the diagonal screwing movements which take place at the shoulder and hip joints in locomotion can scarcely be exaggerated. A minute study of the positions and muscular arrangements of the shoulder and hip joints respectively is not only desirable but imperative. The exact position of these joints has been already described. As regards the muscular arrangements, it is only necessary to point out that the positions of what may be regarded as corresponding muscles do not exactly agree. This is due to the shoulder joint being, as stated, twisted forward and occupying a position anterior to the hip joint. At first sight it would appear as if the trapezius and deltoid muscles correspond with the glutei or great hip muscles. The former muscles, however, look towards the dorsal and outer surface of the arm, whereas the latter look towards the ventral and inner surface of the leg. Regarded from one point of view, the great pectoral muscles of the chest, which look towards the ventral aspect of the arm, correspond to the glutei or great hip muscles which look towards the ventral aspect of the legs. This being so, it will be safer, when considering the muscular arrangements of the shoulder and hip joints, to include all the muscles which invest these joints in all their aspects, namely, anteriorly, posteriorly, and laterally. The joints in question are ball and socket or universal joints—that is, they admit of circumduction, rotation, flexion, extension, abduction, adduction, &c. In order to elicit their several movements the muscles (superficial and deep) which invest

them must, I find, run in every direction, namely, vertically, obliquely, very obliquely, and transversely. Nothing short of a universal arrangement of muscles and muscular fibres will meet the requirements of universal joints. This arrangement of muscles and muscular fibres actually obtains both at the shoulder and hip joints, as a careful dissection of the parts will show.

The necessity for dealing with the shoulder and hip joints somewhat in detail will be fully appreciated when the great subject of locomotion is discussed further on.

§ 298. Muscular Arrangements on the Anterior, Posterior, and Lateral Aspects in Man—The Shoulder, Hip, and other Muscles connected with Locomotion, the Erect Position, &c.

The erect position profoundly modifies certain portions of the skeletal and muscular system, especially the portions representing the superior and inferior extremities and their terminal parts, the hands, and feet. The superior extremities in man play quite a subordinate part in locomotion; the onus of walking and running falling mainly on the lower extremities. The part played by the superior extremities is confined to diagonal, swinging, pendulum-movements which assist the body, when in forward motion, over its dead points, and materially contribute to its power of adjustment and balance.

The superior extremities in man perform the rôle of auxiliaries in locomotion; in quadrupeds the fore and hind limbs are equally engaged in locomotion.

While the movements which result in locomotion extend to all parts of the superior and inferior extremities, they are most pronounced at the shoulder and hip joints, where the limbs are articulated to the body, and where there are ball and socket or universal joints. The shoulder and hip joints are, on this account, deserving of special attention.

The peculiarity of these joints is that they admit of universality of motion—circumduction, rotation, abduction, adduction, flexion, extension, &c. In particular, they admit of diagonal, screwing, spiral movements which are of the very essence of locomotion in the higher animals. The diagonal screwing movements referred to are well seen at the shoulders and hips in the nude subject in walking and running, as I first indicated in 1867. They are also seen in the walking and running of quadrupeds. They extend to the extremities, and can be traced in the pectoral and caudal fins of fishes in swimming, and the wings of insects, bats, and birds in flying.

It will be convenient at this stage shortly to consider the muscles of the trunk anteriorly, posteriorly, and laterally, especially those connected with the shoulder and hip joints, the upper parts of the arm and thigh bones, and their bearing on the erect position and locomotion.

The erect position modifies, in a marked manner, the muscles on the anterior, posterior, and lateral aspects of the trunk and limbs. As a matter of fact, nearly all the muscles of the body take part in maintaining the position in question.

The most outstanding supporting muscles (erectors) occur on the posterior surface of the body, where they are in immediate proximity to the vertebral column (central axis of support), the ribs, the scapulæ, and the pelvis.

The superior or anterior extremities in man, as has been explained, perform a subordinate part in locomotion. Similarly, they discharge a minor function in keeping the body erect. The carrying out of these important details falls mainly on the inferior or posterior extremities, which, as a consequence, are more fully developed and stronger than the superior or anterior ones.

The muscles on the anterior, posterior, and lateral aspects of the body are so arranged, and their origins and insertions such, that they extend between two or more joints and act as balustrades or supports to the joints. As the muscles are attached to certain spiral areas on the bones of the trunk and lower extremities, it follows that the joints are not permitted to yield beyond a certain point, and are, in a sense, rendered immobile. The extent of the immobility is determined, in a large measure, by the will of the individual, and varies according to circumstances. As proof that the chief supporting muscles of the body are situated posteriorly, it may be stated that there is much greater freedom of movement on the ventral than on the dorsal aspect. Thus, while it is easy to curve the body and to cause the head to move through a quarter of a circle or thereby in a ventral or forward direction, it is difficult, unless in the case of trained gymnasts, to curve the body and move the head in a dorsal or backward direction through more than an eighth of a circle. The axis of motion for these movements is an imaginary line drawn through the vertebral column when the body is in the erect position.

What is true of the trunk is also true of the limbs; they can be flexed or folded and made to pass through comparatively large angles in a forward direction, but cannot be extended beyond a certain point in a backward direction. The movements of the body and of the limbs are confined within certain limits; a state of things

necessitated alike by the erect position and by the requirements of locomotion. The peculiarities of the erect position are fully gone into at p. 1060.

The superficial and deep muscles of the ventral and dorsal aspects of the trunk are delineated at Fig. 265 (*a*, *b*, *c*, and *d*).

A reference to Fig. 265 (*b*) shows that the muscles on the posterior aspect of the trunk, as on the anterior

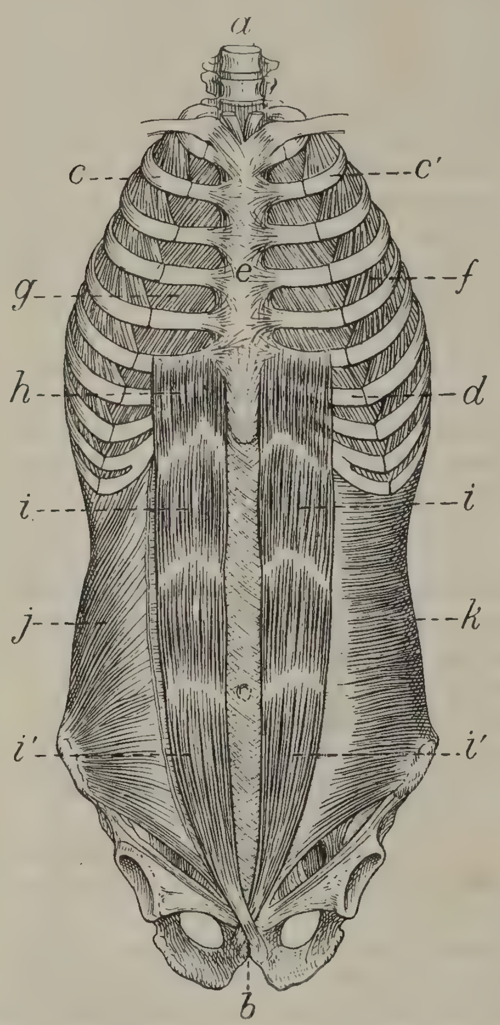


Fig. 265 (*a*).

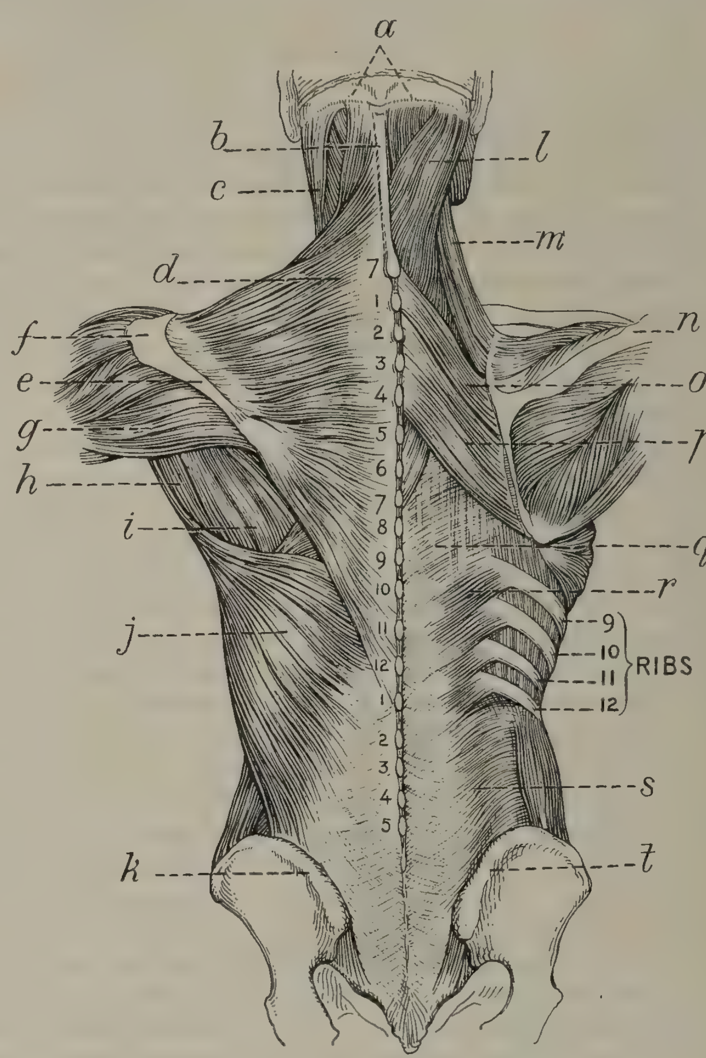


Fig. 265 (*b*).

Fig. 265 (*a*).—Anterior view of the deep muscles of the thorax and abdomen in man (the recti abdominis, which are superficial, excepted). *a*, Spine; *b*, symphysis pubis; *c*, *c′*, ribs; *d*, cartilages; *e*, sternum; *f*, external intercostal muscles; *g*, internal intercostal muscles; *h*, attachment of the rectus abdominis to the cartilages of the ribs; *i*, *i′*, recti abdominis; *j*, the internal oblique; *k*, transversalis.

Fig. 265 (*b*).—Posterior view of the superficial and certain of the deep muscles of the back in man. On the left side is exposed the first layer; on the right side, the second layer, and part of the third. *a*, Occipital bone with superior curved line; *b*, ligamentum nuchæ; *c*, sterno-mastoid; *d*, trapezius; *e*, spine of scapula; *f*, acromion process of scapula; *g*, deltoid muscle; *h*, teres major; *i*, infra spinatus; *j*, latissimus dorsi; *k*, crest of the ilium; *l*, splenius capitis et colli; *m*, levator anguli scapulæ; *n*, spine of scapula with supra-spinatus above and supra-spinatus beneath it; *o*, rhomboideus minor; *p*, rhomboideus major; *q*, vertebral aponeurosis; *r*, *r′*, serratus posticus inferior; *s*, lumbar aponeurosis; *t*, spine of ilium; ninth, tenth, eleventh, and twelfth ribs. The numerals read from above are: 7, spine of seventh cervical vertebra; 1 to 12, spines of the twelve dorsal vertebræ; 1 to 5, spines of the five lumbar vertebræ. The lowest spines are those of the sacral vertebræ, which are not numbered.

aspect (Fig. 265 (*a*)), are symmetrically arranged. There is, further, a certain agreement between those of the shoulder and hip joints, and between those of the limbs, as shown at Fig. 255, p. 1030. The symmetry and general agreement referred to are necessary to secure the proper balance of the body, and to produce a series of similar homologous movements in the upper and lower extremities, especially noticeable in quadrupeds which walk and run on all fours.

The muscles of the back are divided into no fewer than five layers. The superficial or first layer consists of two great fan-shaped muscles on either side, namely, the right and left trapezius muscles, and the right and left latissimus dorsi muscles. The second layer (on one side) is composed of the levator anguli scapulæ muscle, the rhomboideus major and minor. The third layer includes the serratus posticus superior and inferior, the splenius

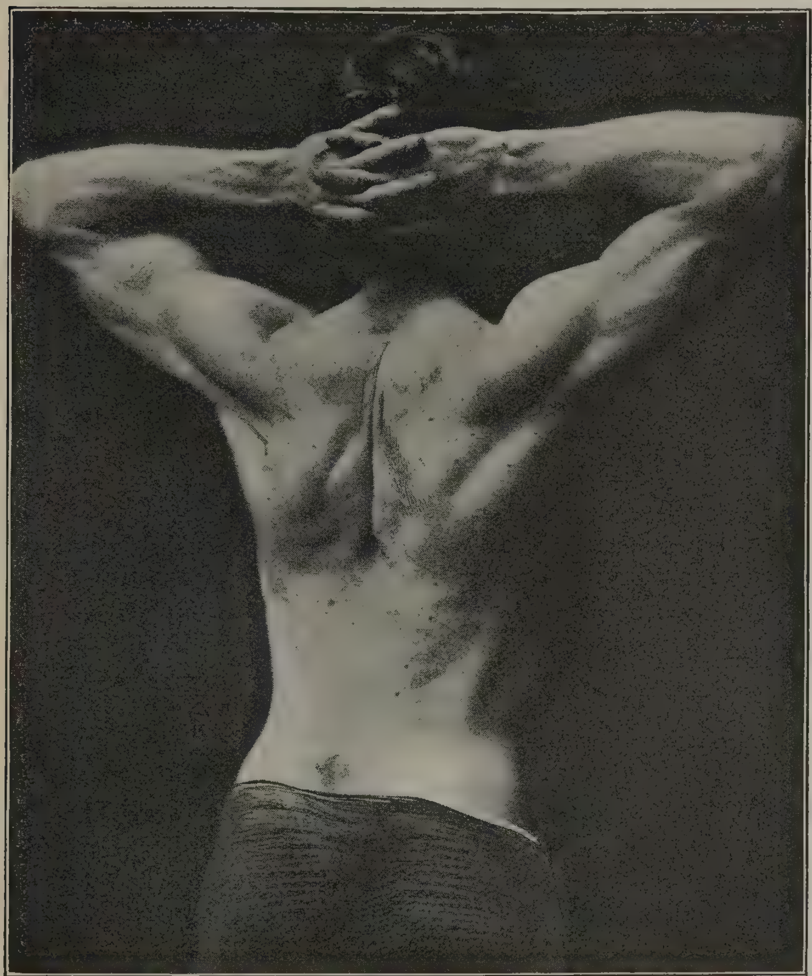


Fig. 265 (*c*).

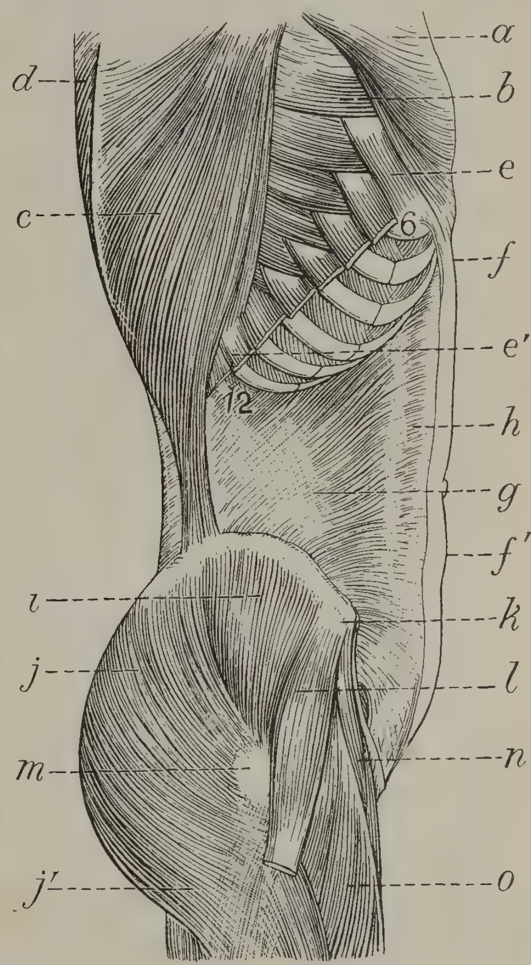


Fig. 265 (*d*).

Fig. 265 (*c*).—Photograph giving a dorsal view of an athlete with the arms raised and the muscles of the arms and scapulæ firmly contracted and thrown into violent action. The muscles of the shoulder joints and the shoulder blades are particularly well seen. They appear under the skin as great, muscular, rounded masses. This is especially the case with the deltoid and biceps muscles; the former on the left side assuming a horseshoe shape on the top of the left shoulder; the latter standing out boldly where the deltoid tapers to a blunt point. The posterior edges of the scapulæ are pressed firmly together, and the various muscles connected with these bones are thrown out into strong relief. Compare with Fig. 265 (*b*), where the muscles are carefully dissected, and the reader can study them at leisure.

Fig. 265 (*d*).—Lateral view of the muscles of the thorax, abdomen, and hip (human)—the external oblique muscle being removed. *a*, Lower portion of the great pectoral; *b*, lower digitations of the serratus magnus from the fourth to the eighth ribs; *c*, lower costal attachments of the latissimus dorsi; *d*, trapezius—one of the great fan-shaped muscles of the back; *e*, *e′*, divided attachments of the external oblique muscle left in connection with the ribs; *f*, *f′*, aponeurosis of the external oblique muscle divided in front of the recti; *g*, internal oblique muscle; *h*, line where the internal oblique muscle divides to form the sheath of the rectus muscle; *i*, gluteus medius muscle; *j*, *j′*, gluteus maximus muscle; *k*, anterior superior spinous process of the ilium; *l*, tensor vaginæ femoris; *m*, trochanter major; *n*, spine of pubes; *o*, rectus femoris.
The numerals 6 to 12 indicate the ribs counted from above downwards (after Henle).

capitis and splenius colli. The fourth layer is made up of the erector spinæ, sacro-lumbalis, musculus accessorius ad sacro-lumbalem, longissimus dorsi, and spinalis dorsi. The fifth or deepest layer includes the semi-spinalis dorsi and colli, multifidus and rotatores spinæ, the supra and inter spinales, extensor coccygis, inter-transversales, rectus posticus major and minor, obliquus superior and inferior.

The muscles of the posterior cervical region are the cervicalis ascendens, transversalis cervicis, trachelo-

mastoid, complexus, biventer cervicis, and spinalis cervicis. To the muscles mentioned above, the several fasciæ, aponeuroses, and ligaments of the back are to be added. These act powerfully in keeping the several parts of the body in position and in shape. To this end the tendons of the muscles, in not a few instances, contribute.

The muscles on the anterior or ventral aspect of the body are the pectoralis major and minor, the intercostales externi and interni, infra costales, triangularis sterni, levatores costarum, the rectus abdominis, pyramidalis, the external and internal oblique abdominal muscles, and the transversalis abdominalis, quadratus, &c.

On the ventral, as on the posterior aspect of the body, there are several important retaining fasciæ, aponeuroses, ligaments, and tendons.

The muscles of the anterior cervical region are the rectus capitis anticus major and minor, rectus lateralis, and longus colli.

On the side of the body the following muscles are to be noted: the scalenus anticus, medius, and posticus, the deltoid, and the muscles on the outer parts of the arm and thigh.

The muscles of the trunk anteriorly, posteriorly, and laterally, have, as fixed points, every coign of vantage afforded by the vertebral column, the clavicles, scapulæ, ribs, pelvis, and limbs. This enables them to control and limit the movements of all the joints in the body, and to maintain the erect attitude. In this they are assisted, as has been pointed out, by the fasciæ, aponeuroses, ligaments, and tendons found in the several regions; these forming passive but powerful supporting and retaining structures.

Perhaps the point of greatest interest, so far as locomotion is concerned, is to be found in the obvious connection which subsists between the shoulder and hip joints. The joints in question have appropriately been designated ball and socket or universal joints from the fact that one or other of the parts forming them can be made to move in any direction—forwards, backwards, upwards, downwards, inwards, outwards, &c. They can also be made to rotate and circumduct. The movements at the shoulder joints are more extensive than at the hip joints; a circumstance due to the fact that the scapulæ constitute semi-detached portions of the skeleton, and supply the heads of the humeri or arm bones with movable fulcra. The heads of the thigh bones, on the contrary, are united by strong capsular ligaments within the acetabular cavities of the pelvis; the pelvis itself being a central fixed structure.

The greater range of the superior or anterior extremities in man is necessitated by the numerous functions they are called upon to discharge. In him, in addition to assisting in locomotion, they perform a large number of acts of the highest importance at the bidding of the brain.

While the superior or anterior extremities in man play a comparatively inconspicuous part in locomotion, they are, nevertheless, the most typical structures of their kind, and supply types or models for the fore limbs of the vertebrata as a class. In the human upper limbs, all the movements which occur in the fore limbs of quadrupeds in walking and running—in the flippers of sea mammals, and in the pectoral fins of fishes in swimming—and in the wings of insects, reptiles, birds, and bats in flying, are more or less clearly indicated.

A striking feature in the shoulder and hip ball and socket or universal joints is the distribution of the muscles and muscular fibres which surround or invest them. These muscles and muscular fibres (superficial and deep) run, as explained, in vertical, oblique, very oblique, and transverse directions; an arrangement which enables them to move the superior and inferior extremities in practically every direction. It also allows them to flex and extend and partially to rotate and circumduct the limbs, and so make the limbs effective organs of locomotion, whether for terrestrial, aqueous, or aërial progression. Nothing short of universality of direction in the muscles and muscular fibres can adequately evoke the universality of movement which distinguishes the ball and socket joints from all other joints.

The universality of movement secured for the limbs by the employment of ball and socket joints is emphasised by the presence of lumbrical and interosseous muscles in the hands and feet of animals with five digits, whereby they can divaricate or separate and approximate or close the digits at discretion. In the case of swimming animals with webbed hands and feet, the power of opening and closing the travelling organs is of the greatest possible consequence, as it enables them alternately to seize and evade the water in which they are immersed, and in which they progress. The opening and closing movements referred to extend to the pectoral and caudal fins of fishes, to the wings of certain insects, and to the wings of birds and bats. These points are dealt with further on.

As the subject of locomotion demands that I should describe, more or less in detail, the muscular arrangements of some animal whose limbs furnish its travelling organs, I have chosen those of man for three reasons: (*a*) because his limbs are the most highly differentiated and perfect limbs known; (*b*) because they are under the control of the most highly developed brain in existence; and (*c*) because they display, alike in their structure and function, the most unmistakable evidences of design.

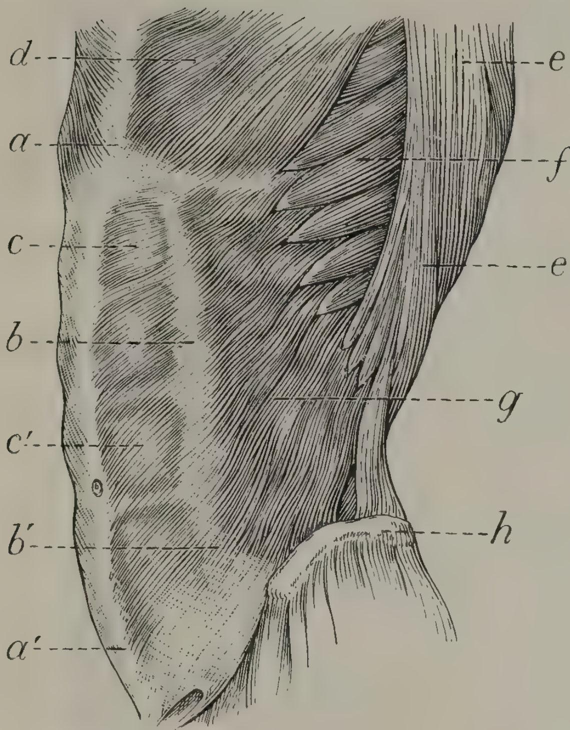


FIG. 266.

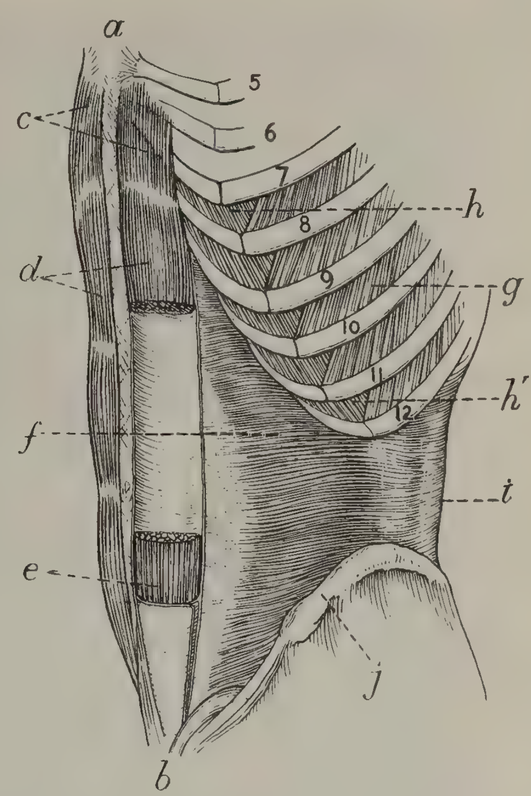


FIG. 268.

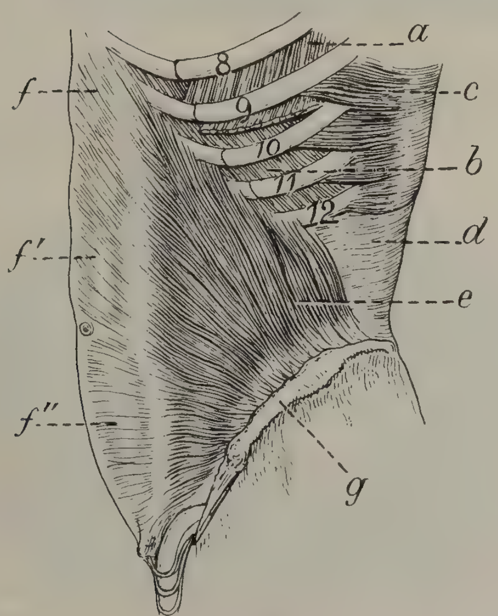


FIG. 267.

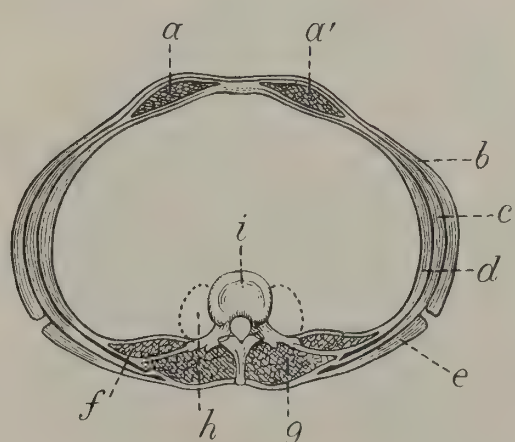


FIG. 269.

FIG. 266.—In this figure the arms are raised. *a*, *a′*, Linea alba or white fibrous mesial line ; *b*, *b′*, semi-lunar fibrous line ; *c*, rectus abdominis muscle (two in number—one on either side of the white line or linea alba), covered with its sheath and partly separated by tendinous intersections (*lineæ transversæ*). The recti muscles play an important part in expiration by dragging down the ribs and sternum, and so reducing the size of the thoracic cavity. They are well seen in Leveillé's three figures (Fig. 255, p. 1030). *d*, Pectoralis major with its muscular fibres drawn up ; *e*, latissimus dorsi with its muscular fibres drawn up ; *f*, serratus magnus ; *g*, obliquus externus ; *h*, crest of the ilium.

When the arms are raised and fixed, the pectoral muscles and latissimus dorsi draw up the ribs as in forced inspiration. In this movement the abdominal muscles (external oblique, internal oblique, transversales and rectal abdominal muscles) take part.

FIG. 267.—*a*, External intercostal muscles ; *b*, internal intercostal muscles ; *c*, serratus posticus muscles inferior ; *d*, lumbar fascia ; *e*, internal oblique muscle ; *f*, *f′*, *f″*, rectus abdominis muscle covered with its sheath ; *g*, crest of the iliac bone.

The external and internal intercostal muscles cross each other obliquely, and when they contract take a prominent part with the

pectoralis minor muscles and serratus magnus muscles in elevating the ribs during inspiration. The ribs are forcibly dragged downwards during expiration by the contraction of the two recti abdominal muscles, aided by the external and internal oblique muscles.

Fig. 268.—*a*, Lower portion of sternum; *b*, symphysis pubis; *c*, *d*, the recti abdominis muscles, showing the vertical direction of their fibres; *e*, the left rectus abdominis muscle cut across; *f*, transversalis abdominis (this muscle by its contractions plays an important part in the expulsive efforts of the abdomen in urination, defæcation, and parturition); *g*, external intercostal muscles; *h*, *h'*, internal intercostal muscles; *i*, lumbar fascia; *j*, crest of the ilium. The recti and transverse abdominal muscles run at right angles to each other, and by their united contractions, aided by the external and internal oblique muscles, diminish the cavity of the abdomen during expiration in all its diameters. The muscles of inspiration contract or shorten when the abdominal muscles relax and elongate, and *vice versâ*—the cavity of the thorax being increased when that of the abdomen is diminished, and conversely. The complemental movements referred to are best seen in forced inspiration and expiration.

Fig. 269.—*a*, *a'*, The two recti muscles cut across; *b*, ditto, the obliquus externus; *c*, the obliquus internus; *d*, the transversalis abdominis; *e*, the latissimus dorsi; *f*, the quadratus lumborum; *g*, the erector spinæ; *h*, the psoas; *i*, portion of vertebral column.

§ 299. Lateral View of the Superficial Muscles of the Human Chest and Abdomen connected with Respiration, Abdominal Expulsive Efforts, &c.

The thoracic and abdominal muscles are arranged in characteristic vertical, oblique, and transverse lines (Fig. 266).

§ 300. Lateral View of the Deeper Muscles (more especially of the Abdomen) connected with Respiration, Abdominal Expulsive Efforts, &c. (Human).

The deeper, like the more superficial muscles of the lateral aspect of the body, run in straight, oblique, and transverse directions (Fig. 267).

§ 301. Lateral View of the Muscles and Ribs of the Left Side of the Body connected with Respiration (Human).

The muscles exposed by this dissection are the external and internal intercostal muscles, the great transverse muscle and the two recti muscles of the abdomen (Fig. 268).

§ 302. Transverse Section of the Human Abdominal Cavity in the Lumbar Region.

The abdominal cavity, which forms a cylinder, is compressed in an antero-posterior direction; the lateral axis exceeding that of the antero-posterior (Fig. 269).

MUSCULAR ARRANGEMENTS AND POSITION OF THE DIAPHRAGM OR PARTITION WHICH SEPARATES THE THORAX FROM THE ABDOMEN (HUMAN)

The diaphragm plays a most important part in the respiratory process, and its structure and movements cannot be too carefully studied. The action of the diaphragm, and that of the respiratory muscles generally, are by no means so well understood as they deserve to be (Fig. 270, A and B).

§ 303. The Human Diaphragm as seen from Above and from Beneath.

The diaphragm, as already indicated, is a muscular partition which separates the thoracic from the abdominal cavity. It moves alternately in a downward and upward direction, in virtue of independent vital rhythmic movements, according as the capacity of the chest is to be increased or diminished in respiration (Figs. 271 and 272).

The muscular fibres of the diaphragm are arranged in straight lines, slightly oblique lines, oblique lines, and transversely as in the ventricles of the mammalian heart, stomach, bladder, &c. The diaphragm, considering its numerous and complicated attachments and relations, its involved structure, and the important functions discharged by it, is one of the most remarkable muscles in the body. It is endowed with independent, rhythmic, centripetal and centrifugal movements, whereby it can flatten and lower itself the one instant, so as to increase the dimensions of the thorax as in inspiration, and can, the next instant, arch dome-fashion in an upward direction, so as to decrease the dimensions of the thorax as in expiration. The alternate increase and diminution of the size of the thorax involves inverse changes in the abdomen; the cavity of the abdomen being enlarged when that of the thorax is diminished, and *vice versâ*.

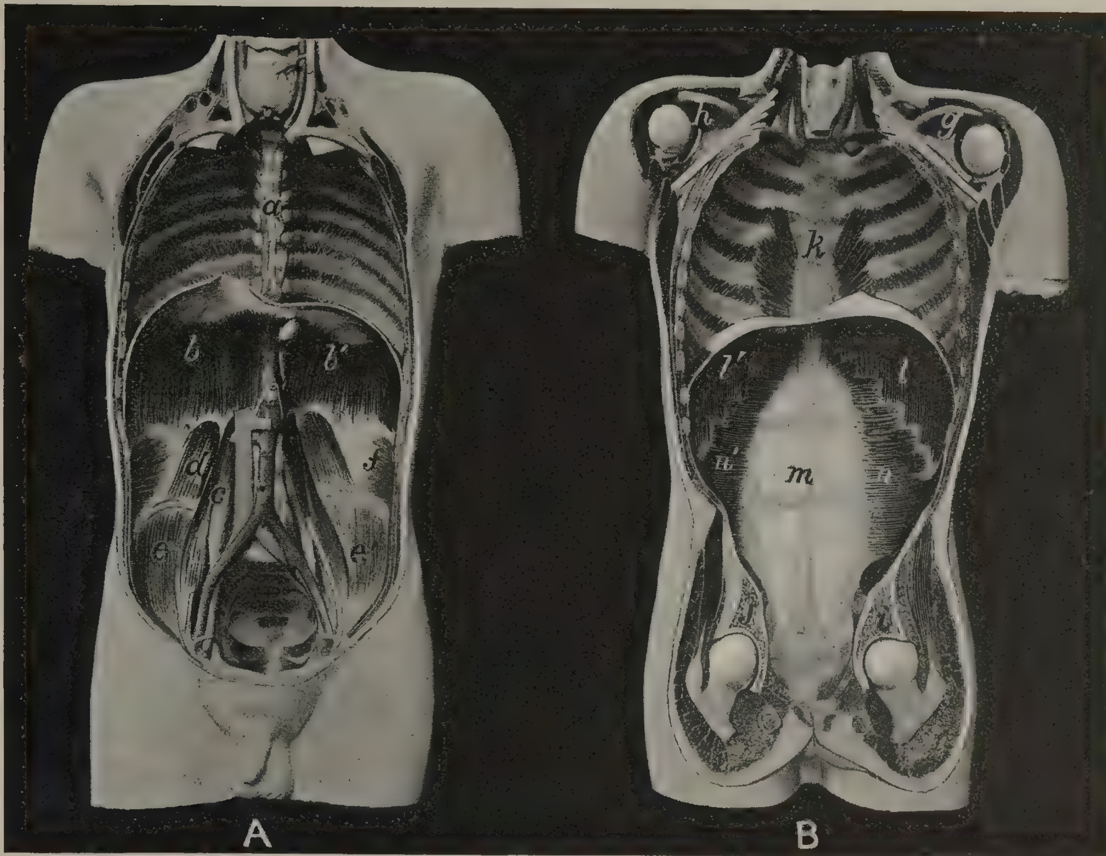


FIG. 270.

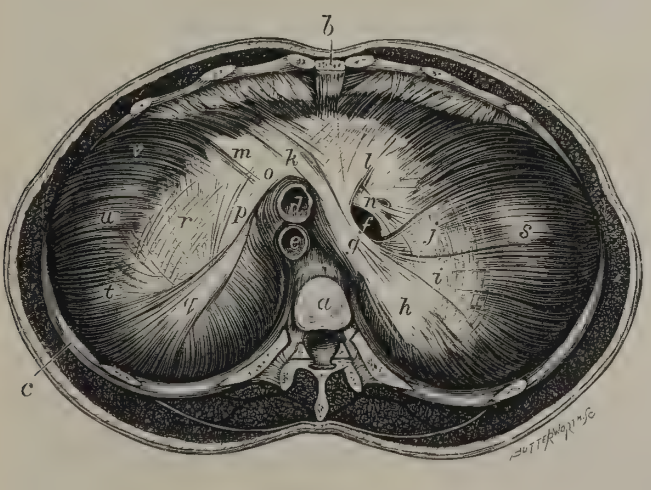


FIG. 271.

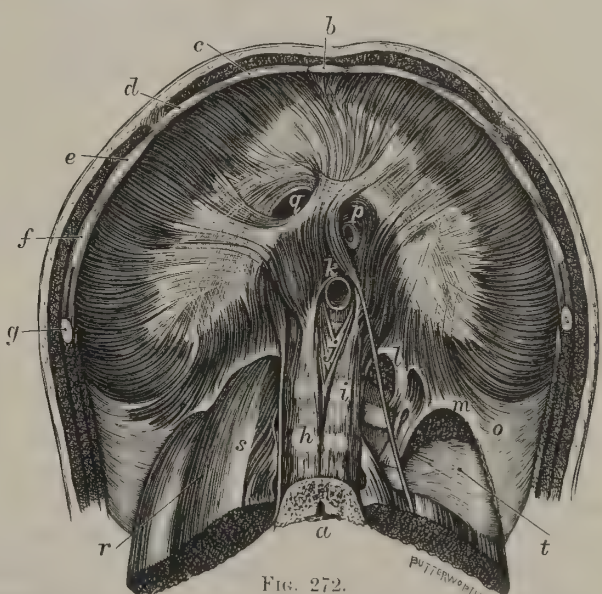


FIG. 272.

FIG. 270.—A. Original photograph of the cavities of the thorax and abdomen as seen anteriorly or in front. Shows the ribs, position of diaphragm, the great blood-vessels, intercostal and other muscles. *a*, Back bone with ribs attached, also intercostal muscles; *b*, *b'*, right and left sides of diaphragm; *c*, psoas magnus and parvus muscles; *d*, quadratus lumborum; *e*, *e'*, iliacus muscles; *f*, transversalis abdominis muscle (the Author).

B. Original photograph of the cavities of the thorax and abdomen as seen posteriorly or from behind. Shows rounded heads of arms and thigh bones, the ribs and intercostal muscles, rectus muscles, and the position of the diaphragm. *g*, Rounded head of right humerus or arm bone; *h*, rounded head of left arm bone; *i*, rounded head of right thigh bone; *j*, rounded head of left thigh bone. The arm and leg bones are provided with ball and socket or universal joints, and can be moved pendulum-fashion in any direction in walking and running. *k*, Sternum or breast bone with sterni muscles, also intercostal muscles; *l*, *l'*, right and left halves of diaphragm; the two recti-abdominal muscles are separated by the linea alba, *m*; *n*, *n'*, the two transverse abdominal muscles (the Author).

FIG. 271.—Muscles of the human diaphragm as seen from above. *a*, Upper surface of the tenth dorsal vertebra; *b*, section of the

lower extremity of the sternum ; *c*, segment of the ninth rib ; *d*, orifice of the œsophagus ; *e*, section of the aorta ; *f*, opening for the vena cava; *g*, middle portion of the oblique fibrous band which separates the opening for the vena cava from the orifices of the œsophagus and the aorta ; *h*, *i*, *j*, the origins of the fibrous oblique band which forms the thoracic surface of the right leaf of the diaphragm ; *k*, *l*, triangular expansion of the oblique fibrous band in the anterior middle leaf of the diaphragm ; *m*, middle aponeurotic suture of the right and left leaves of the diaphragm blended with the triangular expansion of the oblique fibrous band ; *n*, portion of the semicircular posterior band which forms the external boundary of the vena cava ; *o*, *p*, *q*, portion of the semicircular band in front of the œsophageal opening on the left leaf of the diaphragm ; *r*, aponeurotic bundle of the left leaf of the diaphragm ; *s*, the hepatic arch of the diaphragm ; *t*, splenic portion of the left half of the diaphragm ; *u*, *v*, gastric portion of the left half of the diaphragm (after Bourgery).

Fig. 272.—Muscles of the diaphragm as seen from below. *a*, Fourth lumbar vertebra sawn through ; *b*, tip of xiphoid cartilage ; *c*, seventh costal cartilage ; *d*, eighth ditto ; *e*, ninth ditto ; *f*, tip of tenth costal cartilage ; *g*, tip of eleventh ditto ; *h*, expansion of tendon of right pillar (third vertebra) ; *i*, expansion of tendon of left pillar (second vertebra) ; *j*, crossing of the tendinous fibres of the two pillars on the second vertebra ; *k*, fibrous arch of the aortic opening ; *l*, internal fibrous arch ; *m*, external ditto.

Left side.—*n*, Band of insertion of the two arches to the second and third transverse apophyses of the second and third lumbar vertebræ.

Right side.—*o*, Attachment by round ligament to the summit of the twelfth rib ; *p*, œsophageal opening between the pillars ; *q*, elliptical opening for the passage of the inferior vena cava ; *r*, superior extremity of the psoas magnus (right side) ; *s*, superior extremity of the psoas parvus (right side) ; *t*, posterior aponeurosis of the transversalis muscle (after Bourgery).

The diaphragm is a moving musculo-tendinous partition which rises and falls during the respiratory movements very much as the auriculo-ventricular valves rise and fall between the auricles and ventricles during the systole and diastole of the heart. There is this difference. The movements of the diaphragm are vital : those of the auriculo-ventricular valves, vito-mechanical. The movements of the diaphragm are fundamental, as in the case of the heart. They are not under the influence of the will, and go on day and night so long as life lasts. Paralysis of the diaphragm sooner or later results in death. Even a disturbance of the rhythms of the diaphragm, as in asthma, produces profound respiratory derangements resulting in the most alarming and painful choking sensations.

I am aware that the majority of physiologists are of opinion that the diaphragm can only contract and flatten itself in inspiration, and that during expiration it is mechanically pushed up and arched by the action of the viscera beneath it. This view, however, is opposed to the possession by all muscles (especially the involuntary ones) of a double power, whereby they contract and shorten centripetally, and dilate and elongate centrifugally. The mechanical view of the action of the diaphragm is of a piece with that which makes the blood move the heart ; the heart being expressly formed to move the blood. It is based on the theory of irritability and artificial stimulation, than which nothing can be further from the truth.

The whole subject of respiration requires to be reconsidered. It is, strictly speaking, an involuntary act, yet it is largely performed by striated and what are, in the present day, regarded as voluntary muscles. It is true we can hold in the breath voluntarily for one or more minutes, and can voluntarily make forced inspirations and expirations ; but the voluntary effort cannot be long continued, and a period arrives, and arrives quickly, when, *nolens volens*, the respiratory movements assume their normal, rhythmic, involuntary character. Seeing the majority of the muscles which take part in respiration are red striated muscles, it follows, that to them must be ascribed habitual involuntary movements similar to those which occur in the heart, which is also composed of striated muscle.

§ 304. Superficial Muscles of the Left Chest and Front of the Left Arm (Human).

These muscles form typical muscular groups, and, as such, are deserving of special study (Fig. 273).

The powerful pectoralis major and deltoid muscles, in conjunction with the latissimus dorsi and scapular muscles (teres major, teres minor, supra spinatus, infra spinatus, and subscapularis), play an important part in the ball and socket movements of the shoulders, and the partial rotation of the arm, on which the curves and screwing motion performed by the shoulders and anterior extremities of bipeds and quadrupeds in walking and running, the flippers of sea mammals (seal, walrus, sea-lion, &c.), in swimming, and the wings of birds and bats in flying, depend.

The muscular fibres of the pectoralis major and deltoid run practically in every direction, namely, in nearly straight lines, slightly obliquely, obliquely, and transversely, as in the ventricles of the heart, stomach, bladder, uterus, and diaphragm. They can therefore take part in elevating, depressing, rotating, and circumducting the arm. Only muscles with fibres running in several directions are adapted to universal joints.

The muscles of the shoulder and arm are so arranged, and their origins and insertions such, that circumductory, rotatory, and spiral movements of the parts named become a necessity. The spiral origins and insertions of the muscles can be traced on the bones. In the forearm, the spirality is well marked, and if the spiral action of the spiral muscles, bones, and joints be carried beyond a certain point, pronation and supination of the hand occur. The circumductory, rotatory, and spiral movements are not confined to the shoulder and arm, but extend to the forearm and hand.

A similar arrangement of the muscles, bones, and joints occurs at the hip and leg as a whole, as is well seen at Fig. 265 (*d*), p. 1039, and Fig. 285, p. 1053, and in the three spirited figures by Leveillé (Fig. 255, p. 1030).

The deltoid muscle elevates the arm, and the pectoralis major, aided by the latissimus dorsi and teres major, depresses it to the side of the chest. Acting singly, the pectoralis major draws the arms toward the front of the chest. When the arms are elevated and fixed, the muscles in question act upon the ribs, and elevate them and

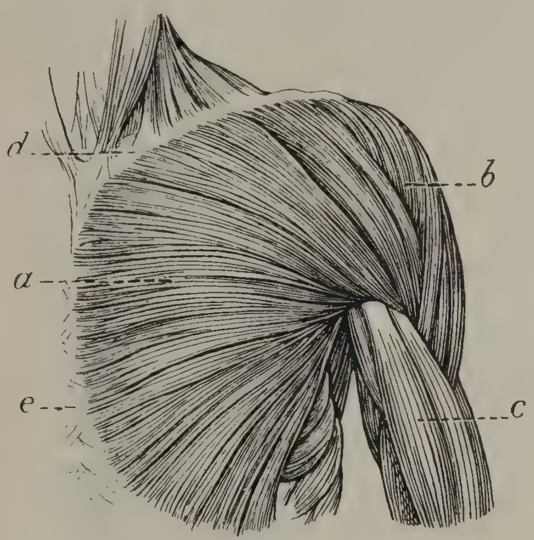


FIG. 273.

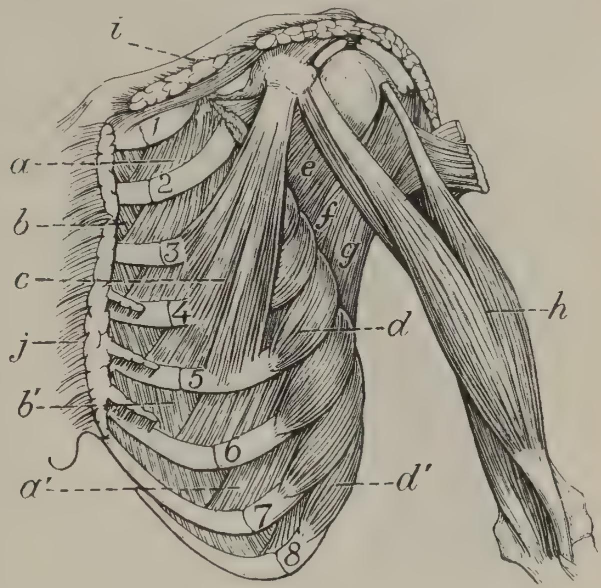


FIG. 274.

FIG. 273.—Superficial muscles on the left chest and arm (human). *a*, The great fan-shaped muscle known as the pectoralis major; *b*, the deltoid muscle; *c*, the biceps muscle; *d*, the clavicle; *e*, the sternum.

FIG. 274.—*a*, *a'*, External intercostal muscles; *b*, *b'*, internal intercostal muscles. The external and internal intercostal muscles when they contract ruck up the ribs and force the sternum or breast bone outwards. *c*, Pectoralis minor; this muscle is a powerful elevator of the ribs. The ribs are pulled down by the contraction of the rectus abdominal muscles, aided by the external and internal oblique muscles. *d*, *d'*, Serratus magnus muscle. This is an elevator of the ribs. *e*, Subscapularis muscle; *f*, teres major; *g*, latissimus dorsi. These three muscles rotate the humerus in the direction of its length. *h*, Biceps muscle. This flexes the forearm on the arm. *i*, Clavicle; *j*, pectoral muscle cut across.

expand the chest, as in forced inspiration. Asthmatic patients, during a paroxysm of that painful complaint, invariably attempt to fix their shoulders against something, and so relieve themselves.

The biceps and brachialis anticus flex the forearm on the arm: the triceps extends it. Other muscles, not represented, perform the movements of pronation and supination of the forearm and hand.

§ 305. Deep Muscles of the Chest and Superficial Muscles of the Front of the Arm (Human).

These muscles are mainly engaged in elevating the forearm and the ribs, and in enlarging the cavity of the thorax during inspiration (Fig. 274).

§ 306. Muscles of the Human Arm, Forearm, and Hand.

These muscles have been selected for description because they display the same general arrangements as those met with in the face, head, neck, thorax, and abdomen, and because they throw much light on the muscular arrangements and movements which prevail in the fore limbs of quadrupeds; the flippers of sea mammals (seal, walrus, sea-lion, &c.); and the wings of birds and bats. They especially illustrate how the movements of circumduction, rotation, pronation, supination, abduction and adduction are produced. They also show how flexion and extension of the limbs are effected, and how the digits or fingers can be alternately spread out and brought together. The movements of separating and approximating the fingers are seen to advantage in the swimming of the seal, walrus, and sea-lion, where the hands and feet are alternately increased and diminished in size (see Figs. 249, 250, and 251, pp. 962 and 964); in the swimming of the fish, where the rays of the pectoral and caudal fins are alternately divaricated and approximated; in the flying of the bird, where the primary and other feathers are made

to spread out, close, and overlap during the down stroke and to open up and separate during the up stroke; in the flight of the bat, where the greatly-developed attenuated digits are made alternately to open out and come together according as the wings are extended or flexed.

§ 307. Muscles occurring on the Dorsum of the Scapula, and the Back of the Arm (Human).

The scapular or shoulder muscles (Fig. 275 *a*, *b*, *c*, *d*) pursue various oblique directions, and run at nearly right angles to the humerus or arm bone (*g*). The sub-scapular muscle (not seen in the figure) pursues a similar direction. As all these muscles arise from the scapula and are inserted into the head and upper part of the humerus or arm bone, they play an important part in the rotation and circumduction of the arm and superior limb as a whole. They invest the ball and socket or universal joint of the shoulder, which they move in a great variety of directions. They take part in the twisting, spiral, curved, and pendulum movements of the superior extremity, and in the formation of the figure-of-8 trajectory made by it and the inferior extremity of the opposite side of the body in walking and running. Similar muscles occur at the buttock or hip joint, which see (Fig. 265 (*d*), p. 1039, and Fig. 285, p. 1053).

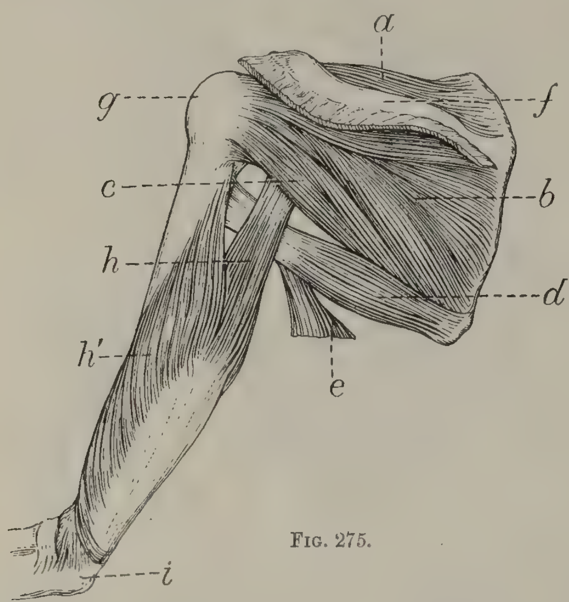


FIG. 275.

FIG. 275.—*a*, Supra spinatus; *b*, infra spinatus; *c*, teres minor; *d*, teres major; *e*, latissimus dorsi; *f*, spine of scapula and origin of deltoid muscle; *g*, humerus or arm bone; *h*, *h′*, triceps; *i*, elbow joint.

The twisting, rotatory, curved movements referred to extend to the forearm and hand, and have great significance when viewed in connection with the spiral action of the pectoral fins of fishes, the flippers of sea mammals, and the diving and flying wings of birds. Elaborate arrangements are made for the tilting and twisting of the extremities in locomotion. The muscles of the superior extremity, as a whole, can produce a reciprocating, reversing, sculling motion.

§ 308. Anterior View of the Superficial Muscles of the Forearm.

These muscles run in straight and slightly oblique lines, and take part in flexing and rotating the limb (Fig. 276). The transverse muscles occur deeper.

§ 309. Anterior View of the Deep Muscles of the Forearm (Human).

The deep muscles run in straight, oblique, and transverse directions. They assist in flexing and rotating the forearm and in pronating the hand (Fig. 277).

The origins and insertions of the superficial and deep muscles of the arm and hand anteriorly, indicate their functions. The straight muscles flex or fold the forearm, wrist, and hand, and the oblique and transverse ones rotate and pronate these parts. Thus the flexor carpi ulnaris and radialis flex the wrist; the flexor sublimis and profundus digitorum flex the phalanges or fingers. The flexor longus pollicis flexes the last phalanx of the thumb. The palmaris longus acts as a tensor of the palmar fascia, and, when this is stretched, it flexes the hand on the forearm. The pronator radii teres and pronator quadratus rotate the radius on the ulna and pronate the hand.

The muscles of the forearm and hand *anteriorly* produce the movements for shortening and rotating the limb in one direction; the muscles which occur *posteriorly* elongating the limb and causing it to rotate in an opposite direction. In virtue of this arrangement the limbs can be shortened and lengthened, and applied at any angle in the performance of particular kinds of work. In quadrupeds in locomotion, the limb, in virtue of these arrangements, is made to seize and let go the earth, its natural fulcrum: in sea mammals and fish in swimming, the flippers and pectoral fins are made alternately to seize and let go the water, which forms a mobile fulcrum: in birds and bats in flying, the wings are made alternately to seize and let go the air, which provides a highly mobile, elastic fulcrum. The quicker the action of flippers, fins, and wings, the better the result.

The movements of flexion and extension, and of rotation in two directions, are fundamental in the locomotion of all the higher animals.

§ 310. **Posterior Surface of the Forearm—its Superficial Muscles (Human).**

These muscles extend the forearm and hand. They also take part in rotating the limb. They run in straight lines and obliquely (Fig. 278).

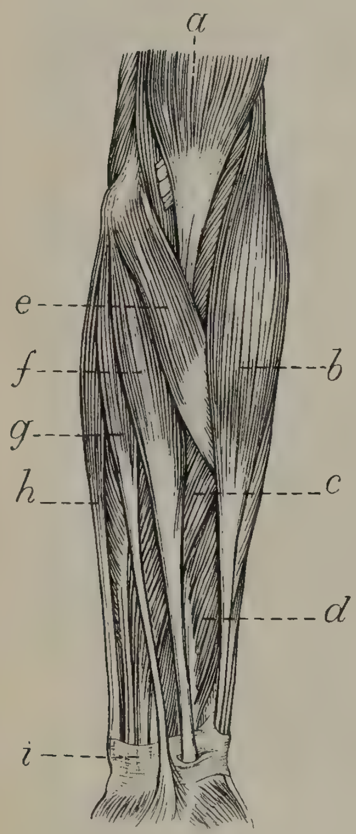


FIG. 276.

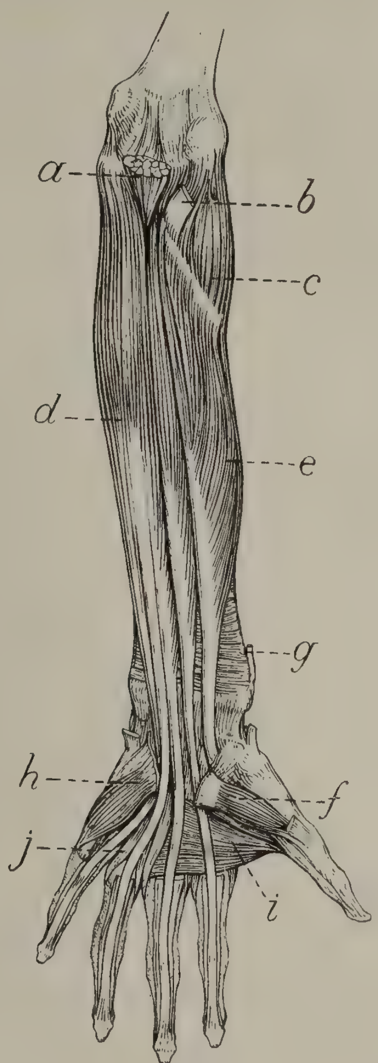


FIG. 277.

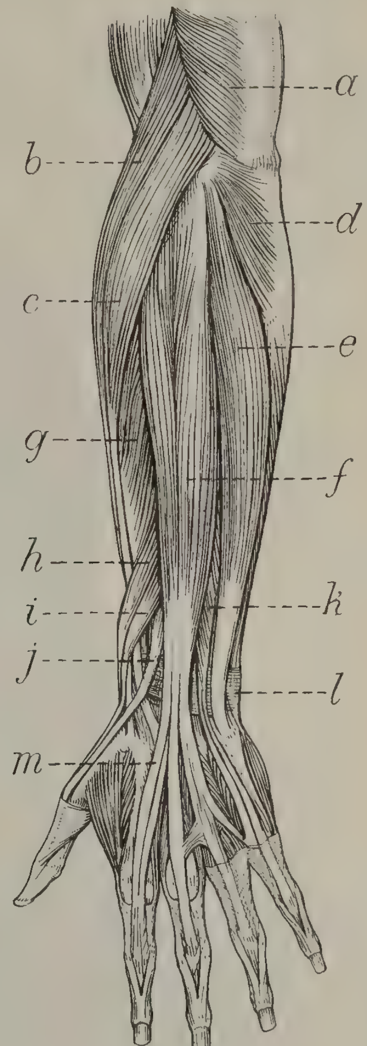


FIG. 278.

FIG. 276.—*a*, The biceps muscle cut across; *b*, supinator longus; *c*, flexor sublimis digitorum; *d*, flexor longus pollicis; *e*, pronator radii teres; *f*, flexor carpi radialis; *g*, palmaris longus; *h*, flexor carpi ulnaris; *i*, transverse fascia which keep the muscles of the arm in position.

FIG. 277.—*a*, The brachialis anticus muscle cut across; *b*, the biceps cut across; *c*, the supinator brevis; *d*, flexor profundis digitorum; *e*, flexor longus pollicis; *f*, flexor brevis pollicis; *g*, pronator quadratus; *h*, opponens minimi digiti; *i*, adductor pollicis; *j*, lumbricales.

FIG. 278.—*a*, Lower portion of triceps; *b*, supinator longus; *c*, extensor carpi radialis longior; *d*, anconeus; *e*, extensor carpi ulnaris; *f*, extensor communis digitorum; *g*, extensor carpi radialis brevior; *h*, extensor ossis metacarpi pollicis; *i*, extensor primi internodii pollicis; *j*, extensor secundi internodii pollicis; *k*, extensor minimi digiti; *l*, transverse fascia of the wrist; *m*, tendon of extensor indicis.

§ 311. **Posterior Surface of the Forearm—its Deep Muscles (Human).**

These muscles run in straight, slightly oblique, and oblique lines. The interosseous muscles which occur in the spaces between the metacarpal bones are penniform in character (Fig. 279).

The interosseous muscles consist of four dorsal and three palmar. Similar muscles occur in the foot, and are figured further on (Figs. 295 and 296, p. 1059). The dorsal interossei abduct the fingers from an imaginary line

drawn longitudinally through the centre of the middle finger, and the palmar interossei adduct the fingers towards the same line.

The names of the deep muscles on the posterior surface of the forearm sufficiently indicate their function.

The muscles of the hand are numerous and complex, and involve a certain amount of detail. Before, therefore, proceeding to a consideration of them it may be of service to refer briefly to the bones of the hand (Fig. 280).

THE BONES OF THE WRIST AND RIGHT HAND—DORSAL SURFACE

These bones are arranged in longitudinal and transverse rows, well seen in Fig. 280.

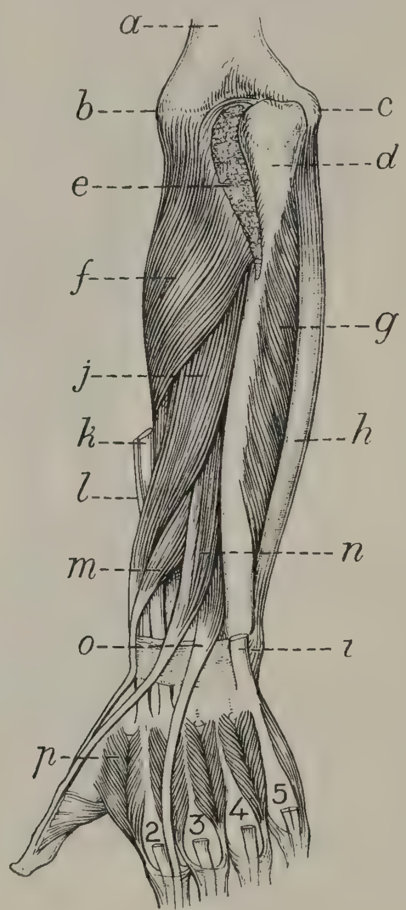


FIG. 279.

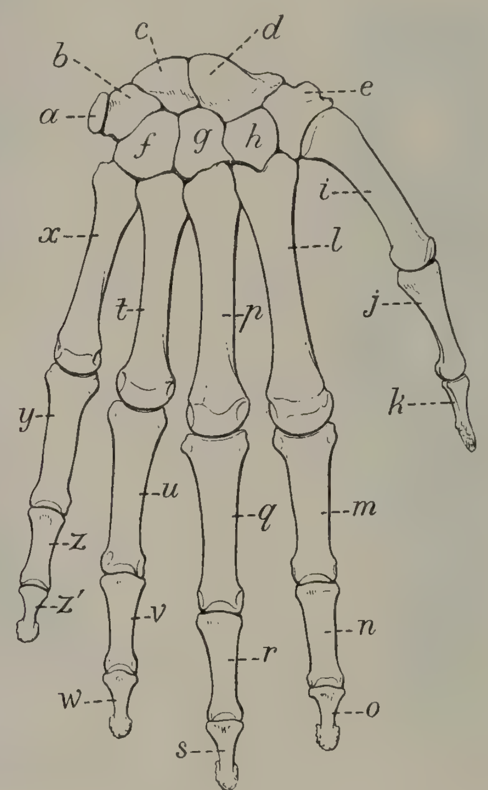


FIG. 280.

FIG. 279.—*a*, Humerus or arm bone; *b*, external condyle of humerus; *c*, internal condyle of humerus; *d*, olecranon; *e*, anconeus muscle cut across; *f*, supinator brevis; *g*, flexor profundus digitorum; *h*, flexor carpi ulnaris; *i*, tendon of extensor carpi ulnaris cut across; *j*, extensor ossis metacarpi pollicis; *k*, extensor carpi radialis brevior; *l*, extensor carpi radialis longior; *m*, extensor primi internodii pollicis; *n*, extensor secundi internodii pollicis; *o*, extensor indicis; *p*, dorsal interosseous muscles (four in number) occurring between the metacarpal bones, which are indicated in numerals (1, 2, 3, 4, 5).

FIG. 280.—*a*, Pisiforme; *b*, cuneiforme; *c*, lunare; *d*, scaphoides; *e*, trapezium; *f*, unciforme; *g*, os magnum; *h*, trapezoides; *i*, metacarpal bone of thumb; *j*, *k*, phalanges of thumb; *l*, metacarpal bone of index finger; *m*, *n*, *o*, phalanges of index finger; *p*, metacarpal bone of middle finger; *q*, *r*, *s*, phalanges of middle finger; *t*, metacarpal bone of ring finger; *u*, *v*, *w*, phalanges of ring finger; *x*, metacarpal bone of little finger; *y*, *z*, *z′*, phalanges of little finger.

A reference to Fig. 280 will show that the bones of the wrist and hand are not only very numerous but that the two upper rows (carpal bones) are curiously wedged and locked within each other, and form an arch, the upper part of which is directed dorsally. Great strength is thus secured to the wrist. As these bones are further firmly attached to each other by short, tough ligaments, additional strength is obtained. Similar ligaments bind the metacarpal and phalangeal bones together, with the result that every part of the wrist and hand is remarkable for its strength. It is also remarkable for its freedom of movement; the freedom varying in certain parts. In the wrist, where the joints are imperfect, the movement is circumscribed and limited, and only admits of the bones

gliding upon each other. In the lower portions of the metatarsal bones and the phalanges, where there are beautiful, saddle-shaped joints, the movements are the freest possible, and permit of flexion, extension, abduction, adduction, and a certain degree of rotation. The hand possesses quite an extraordinary range of motion, and can grasp substances of every conceivable form—spheres, cylinders, cubes, flat surfaces, &c. It can also move to a hair's-breadth in delicate manipulations such as watch making, philosophical instrument making, writing, drawing, and in the arts generally. It is provided with a comparatively large number of muscles and tendons, partly from the forearm and partly from the hand itself. These muscles and tendons—the latter confined in elaborate sheaths—give to the hand its wealth and precision of movement. The intrinsic muscles of the hand (interossei, lumbricales, thumb muscles, &c.) enable it to divaricate and approximate the digits or fingers—a power of immense value to all swimming and flying animals supplied with webs or wings. The hand can boast other advantages. It is covered with a highly sensitive skin—the tips of the fingers being particularly sensitive. It is also furnished with a very full supply of blood, and of sensory and motor nerves. Altogether it is one of the most richly endowed organs of the body, and this was to be expected considering the great multiplicity and variety of work which it is called upon to perform.

§ 312. Muscles of the Hand—Dorsal Surface (Human).

The muscles of the hand are usually divided into three groups : (*a*) those of the thumb, which occupy the radial side of the hand ; (*b*) those of the little finger, which occupy the ulnar side ; and (*c*) those situated in the middle of the palm, which occupy the metacarpal interspaces. The radial or thumb muscles include the abductor pollicis, the opponens pollicis, the flexor brevis pollicis, and the adductor pollicis.

The ulnar or little finger muscles consist of the palmaris brevis, the abductor minimi digiti, the flexor brevis minimi digiti, and the opponens minimi digiti.

The muscles which occupy the middle palmar region are the lumbricales, interossei palmares, and interossei dorsales.

It is not necessary to take up these muscles in the order named, and time will be saved by dealing with them as they occur in dissections of the palmar and dorsal aspects of the hand and corresponding surfaces of the forearm.

§ 313. Muscles, Tendons, &c., of the Left Hand—Palmar Surface (Human).

These muscles, tendons, &c., are given in detail at Fig. 281.

Fig. 281.

Fig. 281.—Shows the tendons of the flexor muscles of the left forearm and hand ; the flexor, abductor, and opponens muscles of the thumb, and the abductor and adductor muscles of the four fingers. *a*, Flexor carpi ulnaris ; *b*, flexor communis digitorum ; *c*, palmaris longus ; *d*, flexor carpi radialis ; *e*, flexor longus pollicis ; *f*, annular ligament of the wrist which keeps the tendons of the forearm in position and allows certain of them free play ; *g*, palmaris brevis cut across ; *h*, opponens pollicis ; *i*, abductor pollicis ; *j*, flexor brevis pollicis (outer head) ; *k*, adductor pollicis ; *l*, flexor longus pollicis ; *m*, abductor indicis ; *n*, first lumbricalis muscle ; *o*, second lumbricalis muscle ; *p*, third lumbricalis muscle ; *q*, fourth lumbricalis muscle ; *r*, abductor minimi digiti ; *s*, flexor brevis minimi digiti ; *t*, tendon of flexor profundus digitorum ; *u*, tendon of flexor sublimis digitorum ; *w*, sheath laid open showing tendons *in situ* ; *x*, *x'*, sheath of flexor tendons intact. The names of the muscles, for the most part, indicate their function.

The thumb, it will be perceived, "is provided with three extensor muscles, an extensor of the metacarpal bone, an extensor of the first, and an extensor of the second phalanx ; these occupy the dorsal surface of the forearm and hand. There are, also, three flexors on the palmar surface, the flexor ossis metacarpi (opponens pollicis), the flexor brevis pollicis, and the flexor longus pollicis ; there is also an abductor and an adductor. These muscles give to the thumb that extensive range of motion which it possesses in an eminent degree."

§ 314. Lumbrical and Interosseous Muscles of the Hand (Human).

These muscles are delineated at Figs. 282 and 283, and are important from the part played by them in alternately separating and approximating the fingers and thumb to increase and diminish the spread of the hand as required (which is well seen in animals with webbed hands and feet).

The lumbrical muscles are four in number, and consist of small fleshy fasciculi which are accessories to the deep flexor muscle. They are depicted and their positions indicated at *n*, *o*, *p*, *q*, of Fig. 281.

They arise by fleshy tendons from the tendons of the deep flexor; the first and second on the radial side (palmar surface) from the tendons of the index and middle fingers; the third from contiguous sides of the tendons of the middle and ring fingers; and the fourth from the contiguous sides of the ring and little fingers. They pass to the radial side of corresponding fingers, and when opposite the metacarpo-phalangeal articulations the tendon in which each terminates is inserted by a broad aponeurosis which becomes continuous with the expansion of the tendon of the extensor communis digitorum on the dorsal surface of each finger.

The interossei muscles, as their name indicates, occur between the metacarpal bones of the hand, and are seven

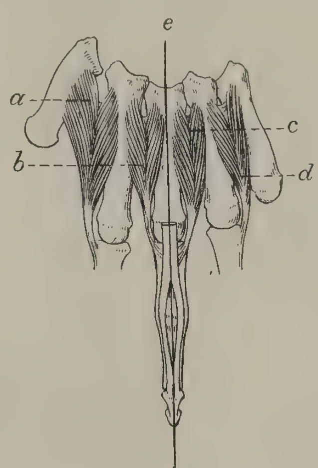


FIG. 282.

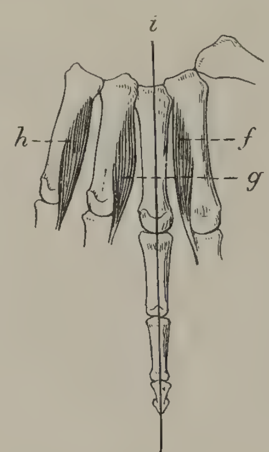


FIG. 283.

FIG. 282.—Shows the four dorsal interossei muscles *in situ*. *a*, First dorsal interosseus muscle; *b*, second ditto; *c*, third ditto; *d*, fourth ditto; *e*, vertical line drawn along the middle finger to which the actions of the muscles are referred. As shown by the insertion of the tendons (*a*, *b*, *c*, *d*), they abduct the fingers from the line in question. The origins and insertions of the dorsal interossei indicate their function. They separate and open out the digits.

FIG. 283.—Shows the three palmar interossei muscles *in situ*. *f*, First palmar interosseous muscle; *g*, second ditto; *h*, third ditto; *i*, vertical line drawn along the middle finger to which the actions of the palmar interossei are referred. As in the dorsal interossei, the origins and insertions of the palmar interossei indicate their functions. They adduct the fingers towards the vertical or standard line. They draw together and approximate the digits. The dorsal and palmar interossei perform diametrically opposite functions. No better arrangements could possibly be devised for alternately divaricating and approximating the digits and so increasing and diminishing the size of the hand.

in number, namely, four dorsal interossei and three palmar interossei. The former are the larger and stronger, and are delineated at Fig. 282. The palmar interossei are given at Fig. 283.

The muscles and tendons of the hand run in straight, slightly oblique, oblique, and transverse directions, and, in virtue of this arrangement, confer a great variety of movement on the hand as a whole. Thus they flex the hand, thumb, and fingers, and cause the thumb and fingers to separate, divaricate, and spread out at one time, and to come together and converge at another time, so as alternately to increase and diminish the area occupied by the hand at any particular period. Precisely the same thing happens in the hands and feet of the walrus, seal, and sea-lion in swimming, in the pectoral and caudal fins of fishes when similarly engaged, and in the wings of birds and bats in flying. In all these cases, the organs of locomotion can be extended and spread out to seize the water or the air the one instant, and flexed and drawn in to let it go the next. This is also true of the feet of the majority of bipeds and quadrupeds which travel on the land. Birds extend or straighten their limbs before placing their feet on the ground, and the moment the feet touch the ground, and the superincumbent weight of the body comes upon them, they spread out and take a firm hold of it. The divaricating and approximating movements of the digits are very well seen in the locomotion of the barn-door fowl, and in the bare feet of a child in walking. When the feet are raised from the ground the digits come together; their approximation being accomplished by a flexing or shortening of the limbs and by a folding or closing of the digits and feet themselves. The solidungulate animals,

such as the horse, form the only exception to what is here stated. In the horse tribe, the feet are solid, and their size is neither increased nor diminished in locomotion. In cloven-hoofed animals, the increase and diminution of the size of the feet in locomotion are considerable; and in the terrestrial animals whose feet display five digits, the change in the size and shape of the feet in walking and running is an outstanding feature. The spread of the feet when in contact with the ground is well seen in the walking of the ostrich and camel, where the digits are less than five in number. In both the ostrich and camel, opportunities for studying which I have enjoyed in Tangiers, Egypt, and elsewhere, the spread of the feet in walking and running is so great as to command the attention of even the casual observer.

The hand in man swings backwards and forwards pendulum-fashion in walking and running, and reciprocates with a diagonal or opposite foot, but this is its sole contribution to locomotion. Its extraordinary powers are only evoked by the operations of volition and the intellectual processes. It is *par excellence* the organ of the mind, and some go the length of asserting that the mind could not be developed without it. The head and the hand certainly reciprocate to an extraordinary extent, and the connection between them is of the closest. No one ever heard of good hands apart from an active intelligent brain.

It is no exaggeration to say that the hand of man is the most highly developed and differentiated organ of its kind. It is at once powerful and elegant, its bones and joints are beautifully modelled, and its muscles are numerous, and adapted to the performance of every conceivable kind of work. Its nerves (sensory and motor) enable it to execute whatever task the mind imposes, and to take cognisance of every object with which it comes in contact. There is nothing, or next to nothing, physically speaking, which the hand cannot accomplish under the guiding influence of the brain. It can expand or open, and flex or close. It can alternately spread out and approximate its digits and move them in a great variety of directions. It can approximate the thumb to the fingers and palm of the hand and promptly withdraw it. It can seize articles of every possible shape. It can wield a sledge-hammer or a pen, and pick up and thread a needle. In all the arts it is the instrument which, guided by the brain, forms the veritable stronghold of construction. It forms the timepiece, guides the loom, builds the ship, raises the bridge, constructs the locomotive, prints the newspaper, wields the brush, and performs untold useful offices. On the whole, it affords one of the best examples of design known. Its presence, apart from a Creator, cannot be explained by any number or combination of adventitious circumstances in time and space. It is no chance organ, and is not indebted for its existence to externalities. It is developed from within and not from without. It is an original creation—an integral and all-important part of the animal to which it belongs. The same is true of the foot. A child born without hands and feet would, if left to itself, inevitably perish.

The emancipation of the hands and arms in man due to his erect position is at the root of all progress. In the quadrupeds, where the hands are not so emancipated, and which walk on all fours, the hands perform a prominent and necessary part of locomotion, and are in constant requisition in moving from place to place. In man, only the feet and lower extremities are so employed; the hands and arms being left practically unfettered and at liberty to carry out the numerous and exacting behests of the will. The erect position not only frees the hands and arms; it also liberates the eyes, so that they can leisurely survey the heavens and every part of the earth's surface. Man is privileged to behold, and in large measure to comprehend, the star-spangled dome under which he lives. He is also endowed with powers which enable him to occupy and conquer the whole earth. Plainly, man is a separate and independent creation. In no animal do we behold the extraordinary combination of hand, eye, and brain which we witness in him. In vain do those who preach *evolution* and *natural selection* endeavour to account for such structures as the hand, sense organs, &c., and to bridge over and fill up the profound gulf which separates him from the monkeys and all animals lower in the scale. His brain is enormously in excess of his requirements as a mere animal, and his possession of perfect hands and arms, between which and the brain there is the most marvellous co-adaptation, coupled with his erect posture, places him in a category by himself and on an eminence to which no animal can ever aspire. All evidence, so far, is in direct opposition to the hypothesis that man is a mere evolution from the lower and lowest animal forms, and all the cunningly devised tables and genealogic trees which endeavour to prove him an animal pure and simple are the veriest figments of the imagination. They assume so much, and take so much for granted, that no reliance whatever can be placed on them. Those of Mr. Darwin and his famous follower, Professor Haeckel, afford no exception.

§ 315. The Muscular Arrangements of the Inferior Extremities in Man.

The muscular arrangements of the inferior extremities in man greatly resemble those of the superior extremities already described. They have, however, their peculiarities, and, as they are the chief organs of locomotion, it is necessary to describe them more or less in detail.

§ 316. Muscles of the Iliac and Anterior Femoral Regions (Human).

These muscles play an important part in keeping the body in an erect position. They run in straight, slightly oblique, and oblique directions. One of them (the sartorius) crosses the front of the thigh and pursues a distinctly spiral course; another (the rectus) affords a beautiful example of a penniform muscle where the muscular fibres diverge from a central raphe as the barbs of a feather diverge from its central stem or shaft. An intimate relation obtains between the pelvis, thigh bone, hip and knee joints on the one hand, and between the pelvis and lower portion of the trunk on the other. The pelvic and thigh muscles connect the several parts named, and co-ordinate the movements of the hip and knee joints (Fig. 284). It is interesting to compare the parts referred to with similar parts in the upper extremity (Figs. 273 and 274, p. 1045).

When the thoracic, abdominal, and other muscles of one side of the body contract and shorten they tend to bend and rotate the body to the same side. It is only when the muscles of both sides of the body are in action, and when they equilibrate each other, that the body is erect and straight.

The complicated circumductory, rotatory, and spiral movements witnessed in the extremities can readily be traced in the head, neck, and trunk.

The spinal column reveals double reversing curves, and is capable of having generated in it, by its intrinsic muscles, well-marked rotatory and spiral movements. At its upper end it furnishes a horizontal circular joint consisting of a bony ring (the atlas) and a pivot (the odontoid process or axis) on which the head rotates to right or left to the extent of nearly a quarter of a turn. The body, when the feet are firmly placed upon the ground, can be made to rotate to the right or left to about the same extent. Into the rotatory movements a certain degree of spirality invariably enters. The body, with the feet on the ground as a fixed point or centre, can be made to circumduct. To these movements the simpler ones of extension and flexion are to be added. Thus the body can be made to bend forwards until the tips of the fingers touch the tips of the toes. It can also be made to bend backwards, though not to the same extent. It can further be made to curve to the right or left side; the degree of lateral movement being considerable, and varying according to the agility of the individual. The various movements of the body can be made to run into each other. Thus the circumductory, rotatory, and spiral movements can be combined with more or less pronounced flexor and extensor movements in antero-posterior and lateral directions, so that a universality of movement may be claimed for the body and the marvellously constructed spinal column.

The movements of the body reappear in the superior and inferior extremities of man and in the fore and hind limbs of quadrupeds. These movements, which have already been described in the superior or upper extremity, are, if possible, better seen in the inferior or lower extremity, to which I now shortly direct attention.

While the circumductory, rotatory, and spiral movements of the inferior extremity extend to the whole limb, they are most pronounced at the buttock and hip joints. There the muscles and muscular fibres run in every direction—vertically, slightly obliquely, obliquely, and transversely. The hip is provided with a universal or ball and socket joint which admits of every kind and degree of movement, and the full powers of which, as indicated, can only be evoked by a universal arrangement of muscles and muscular fibres. The superficial and deep muscular arrangements of the buttock are well seen at Fig. 265 (*d*), p. 1039, and Fig. 285.

At Fig. 265 (*d*) the superficial muscles are given, and at Fig. 285 the deep muscles.

At Fig. 285 the muscles of the posterior of the thigh and knee joint are depicted.

Fig. 285 shows that the muscles of the hip and the posterior surface of the thigh run in straight lines, slightly obliquely, obliquely, and transversely. It also shows that certain of the muscles operate upon the hip joint only, others operating on the hip and knee joints respectively. The relation of the muscles to the joints has an important bearing on the erect position of the body; the muscles conferring on the joints the degree of rigidity necessary under all circumstances. The erect position is due to the configuration of the skeleton and to the arrangement and combined action of the superficial and deep muscles of the inferior extremities, trunk, and neck. To these are to be added several strong fasciæ, aponeuroses, and ligaments.

I enumerate the muscles and their attachments as displayed at Fig. 285 in a direction from above downwards.

The actions of the muscles of the hip and posterior surface of the thigh are well stated by Mr. Henry Gray as follows ("Anatomy," pp. 287 and 288): "The glutei muscles, when they take their fixed point from the pelvis, are all abductors of the thigh. The gluteus maximus and the posterior fibres of the gluteus medius rotate the thigh outwards; the anterior fibres of the gluteus medius and the gluteus minimus rotate it inwards. The gluteus maximus serves to extend the femur, and the gluteus medius and minimus draw it forwards. The gluteus maximus is also a tensor of the fascia lata. Taking their fixed point from the femur, the glutei muscles act upon the pelvis, supporting it and the whole trunk upon the head of the femur, which is especially obvious in standing on one leg.

In order to gain the erect posture after the effort of stooping, these muscles draw the pelvis backwards, assisted by the biceps, semi-tendinosus, and semi-membranosus muscles. The remaining muscles are powerful rotators of the thigh outwards. In the sitting posture, when the thigh is flexed upon the pelvis, their action as rotators ceases,

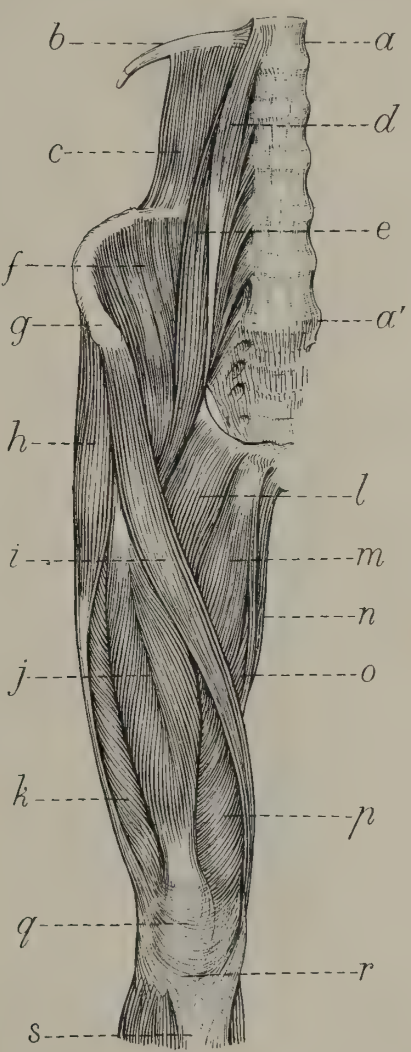


FIG. 284.

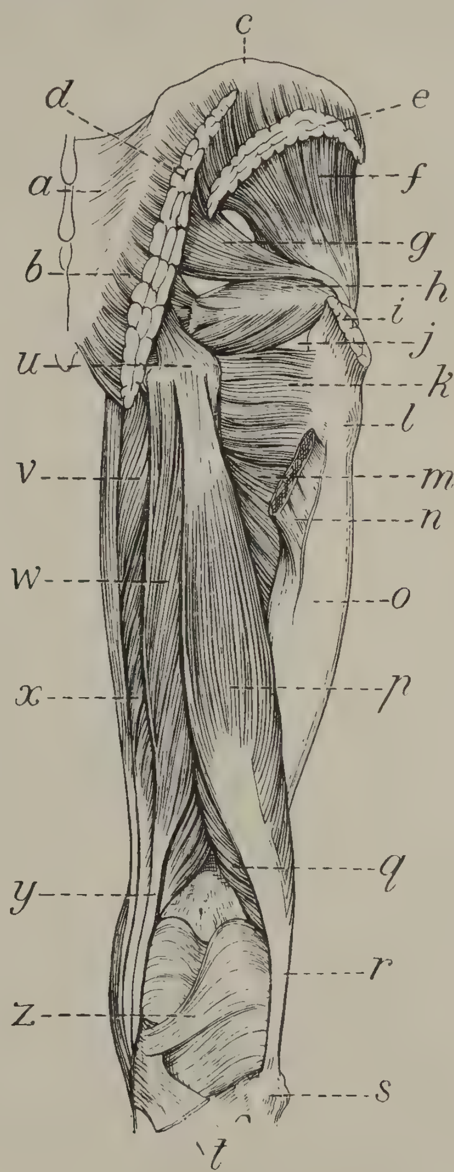


FIG. 285.

FIG. 284.—*a*, *a'*, Lower portion of spinal column; *b*, last rib; *c*, quadratus lumborum; *d*, psoas parvus; *e*, psoas magnus; *f*, iliacus; *g*, crest of the ilium; *h*, tensor vaginæ femoris; *i*, sartorius; *j*, rectus; *k*, vastus externus; *l*, pectineus; *m*, adductor longus; *n*, gracilis; *o*, adductor magnus; *p*, vastus internus; *q*, patella; *r*, tendon of the patella; *s*, tibia.

The following is the account given of the action of certain of these muscles by Mr. Henry Gray: "The tensor vaginæ femoris is a tensor of the fascia lata; continuing its action, the oblique direction of its fibres enables it to rotate the thigh inwards. In the erect posture, acting from below, it serves to steady the pelvis upon the head of the femur. The sartorius flexes the leg upon the thigh, and, continuing to act, flexes the thigh upon the pelvis, at the same time drawing the limb inwards, so as to cross one leg over the other. Taking its fixed point from the leg, it flexes the pelvis upon the thigh, and, if one muscle acts, assists in rotating the pelvis. The quadriceps extensor extends the leg upon the thigh. Taking their fixed point from the leg, as in standing, the extensor muscles act upon the femur, supporting it perpendicularly upon the head of the tibia, thus maintaining the entire weight of the body. The rectus muscle assists the psoas and iliacus, in supporting the pelvis and trunk upon the femur, or in bending it forwards."

FIG. 285.—*a*, Sacrum; *b*, coccyx; *c*, crest of ilium; *d*, gluteus maximus cut across; *e*, gluteus medius cut across; *f*, gluteus minimus; *g*, pyriformis; *h*, obturator internus with the gemellus superior above and the gemellus inferior below it; *i*, tendon of gluteus medius cut across (insertion of); *j*, obturator externus; *k*, quadratus femoris; *l*, great trochanter of the femur; *m*, adductor; *n*, tendon of the gluteus magnus cut across (insertion of); *o*, vastus externus; *p*, long head of biceps muscle; *q*, short head of biceps muscle; *r*, tendon of biceps muscle (outer hamstring tendon); *s*, head of fibula; *t*, head of tibia; *u*, tuberosity of the ischium; *v*, adductor magnus; *w*, semi-tendinosus; *x*, semi-membranosus; *y*, inner hamstring tendons named from without inwards—sartorius, gracilis, semi-membranosus, and semi-tendinosus; *z*, posterior ligaments, &c., of the knee joint.

and they become abductors, with the exception of the obturator externus, which still rotates the femur outwards. When the femur is fixed, the pyriformis and obturator muscles serve to draw the pelvis forwards if it has been inclined backwards, and assist in steadying it upon the head of the femur."

From the account given of the action of the muscles of the hip and posterior surface of the thigh, it will be seen that they are largely *rotators* of the thigh. They also take part in abducting and adducting and in flexing and

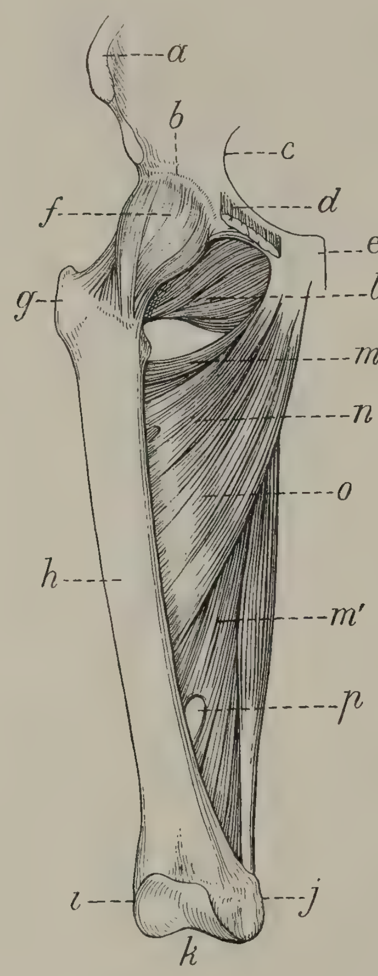


FIG. 286.

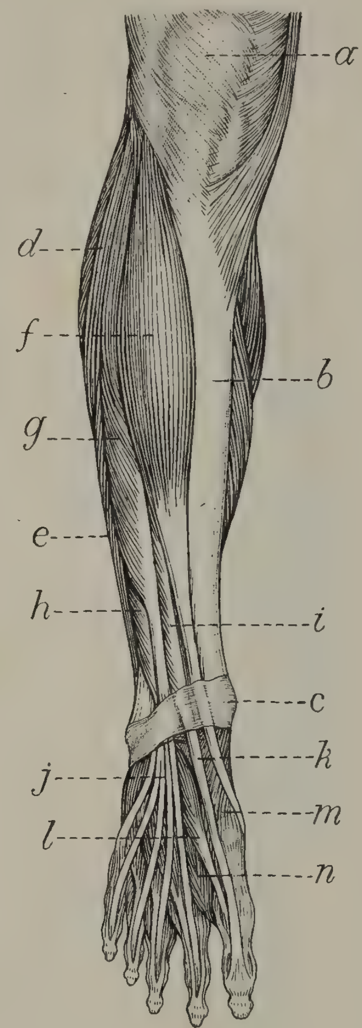


FIG. 287.

FIG. 286.—*a*, Crest of ilium; *b*, upper edge of cavity of acetabulum; *c*, ileo-pectineal line of pelvis; *d*, pectineus muscle cut across; *e*, angle of symphysis pubis of pelvis; *f*, capsular ligament firmly securing rounded head of femur within acetabular cavity of the pelvis; *g*, trochanter major of femur or thigh bone; *h*, shaft of femur; *i*, outer condyle of femur; *j*, inner condyle of femur; *k*, articular surface on lower end of femur which, with the head of the tibia, patella, and ligaments, forms the knee joint; *l*, obturator externus muscle; *m*, *m′*, adductor magnus; *n*, adductor brevis; *o*, adductor longus; *p*, foramen for the passage of blood-vessels, &c.

FIG. 287.—*a*, Patella with knee joint beneath it; *b*, tibia or main bone of leg; *c*, annular ligament with the ankle-joint under it—this ligament keeps the tendons of the leg in position; *d*, peroneus longus; *e*, peroneus brevis; *f*, tibialis anticus; *g*, extensor longus digitorum; *h*, peroneus tertius; *i*, extensor proprius pollicis; *j*, tendons which extend the four toes; *k*, tendon which extends the great toe; *l*, extensor brevis digitorum; *m*, first metatarsal bone; *n*, first dorsal interosseous muscle.

extending the thigh. Lastly, they assist in steadying the pelvis upon the femurs, and so directly contribute in maintaining the erect position. The rotatory and abductor and adductor movements referred to are greatly increased by the action of the great adductors of the inside of the thigh to be described presently.

The importance of the rotatory, abducting, adducting, flexing and extending movements in walking and running in man cannot be over estimated. By them, aided by the pendulum-movements occurring at the hips, the double-curve figure-of-8 trajectories made by the inferior extremities and feet of man in ordinary locomotion are produced.

§ 317. Muscles of the Inner Aspect of the Thigh (Human).

These muscles are important from their direct action on the hip joint and the thigh bones. They extend between the pelvis and thigh bone, and run in straight lines, slightly obliquely, obliquely, and transversely, and are so placed as to move the thigh bone in a great variety of directions. They are given at Fig. 286.

The great muscles on the inner side of the thigh are largely adductors, and, in horse exercise, powerfully press the thighs to the sides of the animal—a movement in which the pectineus takes part. They also, because of their oblique insertions into the femur, rotate the thigh outwards, and so assist the external rotators. If the limb has been abducted, they draw it inwards as in plaiting the legs. The adductor brevis and longus, aided by the pectineus, help the psoas and iliacus muscles to flex or fold the thigh upon the pelvis. All these muscles in walking and running take part in drawing the hinder limb forward in curves,—movements in which the sartorius and gracilis muscles participate. These muscles, when the lower extremities are fixed on the ground, act on the pelvis, and so contribute in maintaining the body in the erect posture.

The muscles on the inner surface of the thigh take a prominent part in locomotion, as they act as rotators and adductors of the limb, and, in certain combinations, perform flexor and abductor movements.

§ 318. Muscles of the Front of the Leg—Anterior Tibio-fibular Region (Human).

The muscles in this region run in straight lines, slightly obliquely, and obliquely. They extend the toes and flex the tarsus, as will be seen by a reference to Fig. 287.

The action of the muscles of the leg is indicated by their names. The extensor longus digitorum and extensor proprius pollicis extend the phalanges of the toes, and, if their action be continued beyond a certain point, flex the tarsus on the leg. The tibialis anticus and peroneus tertius muscles flex the tarsus on the leg. The tibialis anticus, because of the obliquity of its tendon, elevates the inner border of the foot; the peroneus tertius, in conjunction with the peroneus brevis and longus, draws the outer border of the foot upwards and the sole outwards. All the muscles tend to fix the bones of the leg in a vertical position, and to support and strengthen the ankle joint. The interosseous muscles of the foot, consisting of four dorsal and three plantar, are abductors and adductors respectively. Thus the four dorsal interossei abduct the toes from an imaginary line drawn longitudinally through the second toe; whereas the three plantar interossei adduct the toes with reference to a similar line. As in the fingers of the hand, already described, due provision is made for separating and approximating the toes, and due advantage is taken of these arrangements in the extremities of swimming mammals such as the seal, walrus, and sea-lion. In these animals, as has been pointed out, the fingers and toes, with their intervening webs, are separated and opened out during the more effective portions of the strokes in swimming, and approximated and closed during the less effective portions of the strokes. The same thing happens in the pectoral fins and tails of fishes in swimming, and in the wings of birds and bats in flying. But for the power possessed by animals of alternately separating and approximating their fingers and toes, walking, swimming, and flying would, in many instances, be rendered difficult. The power to seize suddenly and as suddenly let go the earth, water, and air (the fulcra provided by nature for the organs of locomotion) constitutes the very essence of locomotion. To this end, the organs in question are spiral in configuration and action, and produce double-curve figure-of-8 trajectories as already explained.

§ 319. Superficial and Certain of the Deep Muscles of the Lower Leg as seen from Behind (Human).

The lower portions and tendons of the muscles of the thigh, and the great gastrocnemius and soleus or calf muscles with their powerful tendon, the tendo Achillis, fall to be considered here (Fig. 288).

The muscles on the posterior aspect of the leg are important from the fact that the great gastrocnemius and soleus muscles, which form the calf of the leg and take such a prominent part in walking and running, occur in this situation. The soleus muscle is placed immediately beneath the gastrocnemius, and both muscles are inserted by means of the tendo Achillis into the posterior portion of the tuberosity of the os calcis or heel bone, which bone when they contract or shorten, they directly elevate. On them the great heel movements of the foot in walking and running chiefly depend.

It is the posterior portion of the heel bone which first comes in contact with the ground in walking and running, and it is also the first part to leave; the toes being the last parts to leave. The body in walking and running rolls over the foot, placed on the ground for the time being, in a direction from behind forwards. The heel and toe

movements, and the rolling forward on the foot, are seen in perfection in the instantaneous photographs of walking and running as given in another part of this work.

It is a remarkable fact, that if the gastrocnemius and soleus muscles and the several parts of the foot be not regularly exercised, as happens in those who wear wooden clogs or those who practise the goose step,[1] the calf of the leg largely disappears. It is also greatly reduced in eunuchs. The opposite condition prevails when the heel

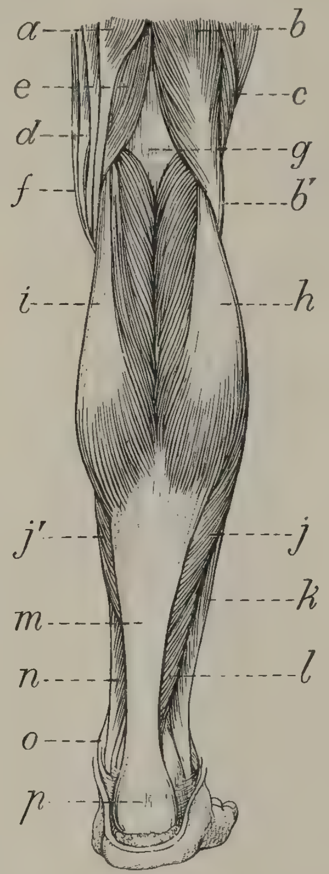


FIG. 288.

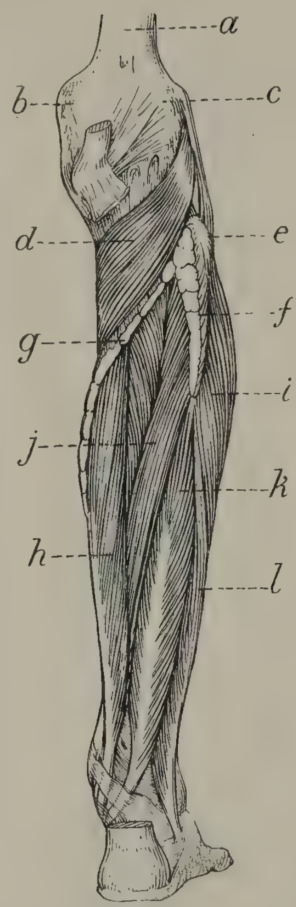


FIG. 289.

FIG. 288.—*a*, Lower part and tendon of the semi-tendinosus ; *b*, *b′*, lower part and tendon of the biceps flexor cruris (inserted into the fibula) ; *c*, lower part of the vastus externus ; *d*, gracilis ; *e*, lower part of the semi-membranosus (inserted into the tibia) ; *f*, small portion of the sartorius ; *g*, popliteal space ; *h*, outer head of the gastrocnemius muscle ; *i*, inner head of the gastrocnemius muscle ; *j*, *j′*, the fibres of the soleus muscle, which with those of the gastrocnemius terminate in the tendo Achillis ; *k*, lower part of tendon of the peroneus longus ; *l*, lower fibres of the peroneus brevis ; *m*, tendo Achillis inserted into the posterior portion of the os calcis or heel bone (*p*) ; *n*, lower part of the flexor longus digitorum ; *o*, portion of tendon of tibialis posticus ; *p*, os calcis or heel bone (after Bourgery).

FIG. 289.—*a*, Lower portion of the femur or thigh bone ; *b*, inner condyle of femur ; *c*, outer condyle of femur ; *d*, popliteus muscle ; *e*, head of fibular bone ; *f*, soleus muscle (fibular origin) ; *g*, soleus muscle (tibial origin) ; *h*, flexor longus digitorum ; *i*, peroneus longus ; *j*, tibialis posticus ; *k*, flexor longus pollicis ; *l*, peroneus brevis.

and toe movements of the foot are duly and daily evoked, as in ballet-dancing and hill-climbing. The ballet-dancer and Highlander are proverbial for their finely-rounded, shapely lower limbs.

The gastrocnemius muscle is the great extensor muscle of the foot, but it acts in a double capacity. While it is an extensor of the foot, it is also a flexor of the knee joint.

When the anterior muscles of the leg fix the ankle joint, it acts as a flexor of the knee. When, on the other hand, the knee is fixed as in complete extension or in sustained action of the extensor muscles, the gastrocnemius acts wholly on the foot, and, in conjunction with the soleus muscle, extends the ankle and astragalo-calcaneal joints. When the gastrocnemius and soleus firmly and fully contract, they lift the os calcis or heel bone from the ground and raise the body on the toes. The tibialis anticus and peroneus tertius muscles flex the foot on the leg.

The actions of the deeper muscles of the leg, situated on its posterior aspect, are given under Fig. 289 above.

[1] In the goose step which I have seen performed by the soldiers in Austria, the flat of the foot is put down before the heel. The movement is ridiculous in the extreme, and outrages nature to a degree scarcely conceivable. It destroys the poise of the body, and utterly subverts the dignity and grace of movement for which the genus *Homo* is remarkable.

§ 320. Muscles of the Back of the Leg—Deep Layer (Human).

The muscles on the posterior aspect of the leg all run obliquely; some of them, such as the popliteus, running very obliquely. They therefore contribute to the spiral and rotatory movements of the limb (Fig. 289).

The popliteus muscle is the only muscle of the leg which acts on the knee joint alone. All the others act on the knee, ankle, and other joints. Its chief function is that of a rotator of the lower leg inwards, as the very oblique direction of its muscular fibres indicates. The tibialis anticus flexes the foot upon the leg and at the same time raises the inner side of the foot; the peroneus tertius, on the other hand, flexes the foot and elevates its outer side. The peroneus longus and brevis extend the foot and turn it outwards. The flexor and extensor muscles of the toes, aided by the lumbricales muscles, act like the corresponding muscles of the hand, already described.

The muscles on the posterior aspect of the leg are of comparatively great size and strength. This will occasion no surprise when it is remembered that they have in some measure to counterbalance the great muscular masses of the thigh, and to perform most important functions in connection with walking, running, and leaping. They also take part in maintaining the erect position of the body.

It will be convenient in this place to give an illustration of the bones of the foot, as these are arranged in two beautiful arches (a longitudinal and a transverse one), which confer great elegance and strength on the foot as a whole (Fig. 290).

BONES OF THE RIGHT FOOT SEEN FROM THE INSIDE (HUMAN)

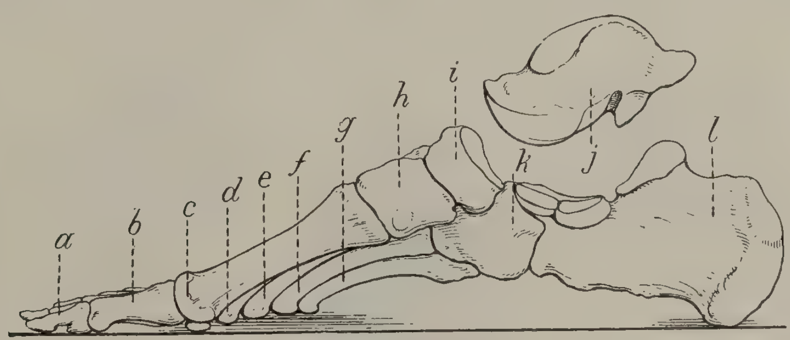


FIG. 290.

FIG. 290.—Shows how the bones of the foot form a longitudinal arch. *a*, Third phalanx; *b*, first phalanx; *c*, first metatarsal bone; *d*, *e*, *f*, *g*, second, third, fourth, and fifth metatarsal bones—these bones, taken together, form the anterior pier or support of the arch; *h*, cuboid bone which forms part of the keystone of the arch, which is completed by the astragalus (*j*); *i*, the os calcis or heel bone, which forms the posterior pier or support of the longitudinal arch. The bones of the foot also form a more or less transverse skew arch, only partly seen in this figure. They are held together by a complex system of strong ligaments. The foot from this circumstance is enormously powerful (after Holden—explained by the Author).

FIG. 291.

FIG. 291.—Photograph of a longitudinal section of the human foot in a young subject. Shows the soft and hard parts *in situ*, and especially the longitudinal, bony arch which gives elasticity and spring to the foot, and the soft, fatty pads of the heel, sole, and ball of the foot, which so effectively cushion it when it comes suddenly in contact with the ground (the Author).

§ 321. Longitudinal Section of the Soft and Hard Parts of the Foot (Human).

The bones, muscles, and soft parts of the foot are so important in walking, running, and leaping, that I append an additional illustration of these parts from a photograph of a dissection of my own, consisting of an original longitudinal section which runs through the centre of the great toe of the right foot of a young individual. The section shows the longitudinal osseous arch to perfection, and, in addition, the beautiful soft padding of the heel, sole, and ball of the foot which, in locomotion, acts as a most perfect buffer between the bones of the foot on the one hand, and the ground on the other. A glance at this section shows how the heel, which first touches the ground in walking and running, and how the ball of the foot and the toes, which are the last parts to leave the ground when the body rolls forward on the foot, are equally protected. The section shows how exquisitely the bones of the foot, whose articular surfaces are covered with smooth cartilages, are adapted to each other. It also shows that certain of the bones of the foot display epiphyses or growing ends, which disappear in the adult condition (Fig. 291).

§ 322. Muscles of the Sole of the Foot—Superficial Layer (Human).

The muscles of the sole are divided into three layers, and the muscular fibres composing them run in straight lines, obliquely, very obliquely, and transversely. The muscles pursuing straight and slightly oblique courses occur

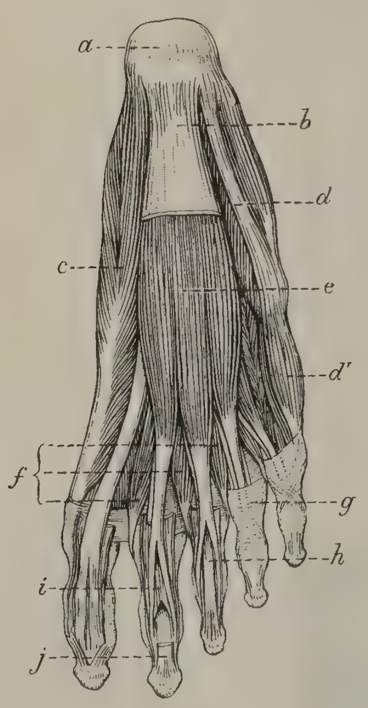


FIG. 292.

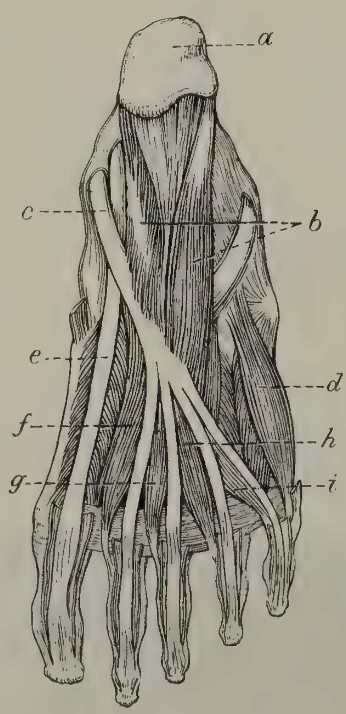


FIG. 293.

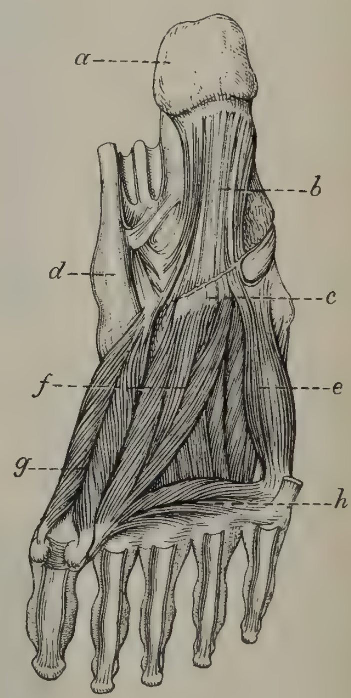


FIG. 294.

FIG. 292.—First layer of muscles of sole of foot. *a*, Os calcis or heel bone; *b*, central portion of plantar fascia; *c*, abductor pollicis; *d*, *d′*, abductor minimi digiti; *e*, flexor brevis digitorum; *f*, lumbricales muscles; *g*, sheath covering a tendon entire; *h*, sheath laid open, exposing a tendon; *i*, flexor brevis perforatus; *j*, flexor longus digitorum.

FIG. 293.—Second layer of muscles of sole of foot. *a*, Os calcis or heel bone; *b*, flexor accessorius; *c*, tendon of the flexor longus digitorum; *d*, abductor minimi digiti; *e*, tendon of the flexor longus pollicis; *f*, *g*, *h*, *i*, the four lumbrical muscles enumerated from the inner side of the foot.

FIG. 294.—Third layer of muscles of sole of foot. *a*, Os calcis or heel bone; *b*, long plantar ligament; *c*, sheath of peroneus longus muscle; *d*, tibialis posticus; *e*, flexor brevis minimi digiti; *f*, adductor pollicis; *g*, flexor brevis pollicis; *h*, transversus pedis.

in the first and second layers; the very oblique and transverse ones being found in the third or deeper layer. The muscles of the superficial or first layer are given at Fig. 292.

§ 323. Muscles of the Sole of the Foot—Second Layer (Human).

The muscles of the second layer differ considerably from those of the first and third layers, as a comparison will show. Among the muscles of the second layer are to be noted the four small but important lumbricales muscles, which are accessories of the four tendons of the flexor longus digitorum muscle. They arise from the tendons in question, pass forward on the inner side of the four lesser toes, and are inserted into the expansions of the long extensor and base of the second phalanx on the side of the phalanx on which they occur (Fig. 293).

§ 324. Muscles of the Sole of the Foot—Third or Deepest Layer (Human).

The muscles of this layer are remarkable for the oblique and transverse directions pursued by them, and for the strong ligaments and tendons which strengthen this portion of the foot (Fig. 294).

§ 325. The Dorsal and Plantar Interossei Muscles of the Foot (Human).

These muscles, like the corresponding muscles in the hand, possess an inherent interest because of the prominent part performed by them in alternately spreading out and divaricating the toes and in bringing together

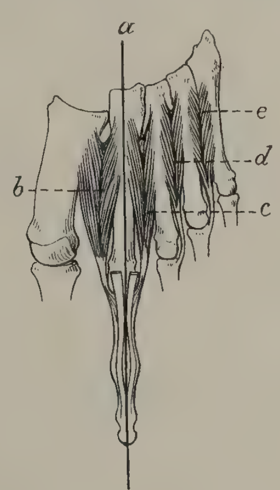


Fig. 295.

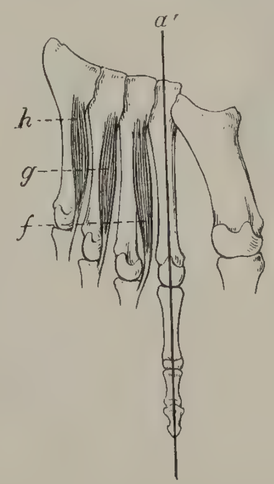


Fig. 296.

Fig. 295.—*a*, Imaginary line or axis drawn through the second toe; *b*, first dorsal interosseous muscle; *c*, second ditto; *d*, third ditto; *e*, fourth ditto.

Fig. 296.—*a′*, Imaginary line or axis drawn through the second toe; *f*, first plantar interosseous muscle; *g*, second ditto; *h*, third ditto.

and approximating them in the efforts of walking, running, and jumping. These movements can only be seen to advantage in the naked foot. The interossei, as explained when describing the anatomy of the hand, are especially important muscles in the swimming of animals with webbed feet, and in their homologues as witnessed in the pectoral and caudal fins of fishes, and in the wings of birds and bats. Like the corresponding muscles of the hand, they consist of four dorsal and three plantar muscles; the former being the larger and stronger. The dorsal interossei muscles arise by two heads from the adjacent sides of the metatarsal bones; their tendons being inserted into the bases of the first phalanges and the aponeurosis formed by the common extensor tendon. The first dorsal interosseous muscle is inserted into the inner side of the second toe; the remaining three being inserted into the outer sides of the second, third, and fourth toes. They are abductors of the toes with reference to an imaginary line or axis drawn through the second toe.

The plantar interossei muscles of the foot—three in number—lie beneath rather than between the metatarsal bones. "They arise from the base and inner shaft of the third, fourth, and fifth metatarsal bones, and are inserted into the inner sides of the bases of the first phalanges of the same toes and into the aponeurosis of the common extensor tendon. These muscles are all adductors towards an imaginary line extending through the second toe" (Figs. 295 and 296).

§ 326. The Foot of Man adapted to the Erect Position.

The erect position distinguishes man from all other animals. The construction and position of his foot largely contribute to the result. In man, when standing, the foot is placed at right angles to the lower extremity and the trunk, and the bones and sole of the foot are so arranged that they rest securely on a flat surface, such as that presented by the ground. The foot rests chiefly on its heel and ball; its under surface forming two arches, a longitudinal and a transverse one, which confer great elasticity and strength, but do not adapt it for grasping rounded bodies, such as branches. In this it differs wholly from the foot of the quadrumana or man-like apes. In them the foot is really a hand, as the term quadrumana (four-handed) indicates.

Those who advocate the theory of evolution endeavour to break down this distinction. It has, however, real significance, and cannot be arbitrarily set aside.

The human foot is especially formed for walking and running on a plane surface—that of the ape for grasping branches and moving on trees, as indicated at Figs. 297 and 298.

The hands and feet of the apes are all grasping organs. In man, the hands only grasp; the feet being reserved for treading upon flat surfaces. Under certain circumstances, the human foot can be trained to grasp and imitate the movements of the hand, but the grasping power, even when artificially developed, is feeble when compared with that of the hand.

Fig. 297.

Fig. 298.

No better proof can be afforded of the real difference which exists between the human foot and that of the ape than is afforded by the special modes of life of the man and the ape respectively. Man is wholly at home on the ground; he is altogether out of place on trees. Similarly, the ape is at home on trees, and out of place on the ground. A man is an indifferent climber—an ape an indifferent walker and runner. The peculiar construction and position of the human and ape foot fully account for the differences in question. An ape, when he attempts to walk on all fours, does so with difficulty and laboriously. His feet are not at all adapted for dealing with a plane surface. Neither are his hands. When he walks, he closes his hands and hobbles along more or less on his knuckles. He is specially formed for an arboreal existence, and to this end his four extremities terminate in hands, which are the best possible organs for seizing and clinging to branches of every size and shape.

The human foot differs very materially from that of the ape, and has an obvious bearing on the erect position. There are other differences; the human pelvis is broader, and occupies a more vertical position than that of the ape. The superior limbs in man are smaller than the inferior ones. In the ape, on the contrary, the superior extremities are longer and stronger than the inferior ones. This follows, because the arms and hands are the chief organs of locomotion in the apes. They swing the body from branch to branch when moving through the trees of the forest; the legs and feet performing a subordinate rôle. In man, the legs and feet are the chief organs of locomotion—hence their greater size and strength as compared with the arms. In the apes, the arms and chest are greatly developed; the body being top-heavy and the centre of gravity high. In man, the body is more accurately poised; the centre of gravity being lower. This is due to the comparatively greater development of the lower half of the body, especially the lower limbs, in man.

The greater weight of the lower limbs in man is necessitated by the erect position, and the leading part they take in locomotion: they have directly to support the superincumbent weight of the body, as well as to move it from place to place.

The question of the length, strength, and weight of limbs is intimately associated with the erect position.

For the apes, where the upper limbs are longer and stronger than the lower ones, the advocates of "evolution" claim the dignity of a semi-erect position, but on wholly mistaken grounds. The apes are forced by evolutionists into the most unnatural semi-erect and vertical positions, and nothing is more common, in works on comparative anatomy where evolution is the guiding principle, than to see the gorilla, chimpanzee, and orang-outang occupying all kinds of impossible *semi-erect* and *erect* attitudes. The true significance of the situation is not that the apes aspire to or trend in the direction of the erect position, but that their upper limbs are elongated and strengthened for the wisest of purposes, namely, that they may swing the body to which they are attached pendulum-fashion, through wide spaces, in their passage from branch to branch in the trees of primeval forests. The body and the centre of gravity in these movements are suspended.

When the hands and feet of the apes are placed on the ground, the front part of the body, because of the greater length of the arms, occupies a considerably higher level than the posterior part, and the long axis of the body is consequently inclined upwards. The upward inclination of the body is, however, an effect and not a cause.

It is the result of the greater development of the upper part of the body and arms as compared with the lower part and legs for an obvious purpose. It is a proof of design, but not of evolution. The object is not the attaining of the erect position, but the securing of serviceable organs of locomotion.

In the case of the gibbons, the upper or anterior limbs are so long that they nearly reach the ground when the animal is temporarily placed in an erect attitude.

Numerous other examples might be cited of hyper-development of the upper limbs.

The common bat supplies an illustration. In this quaint creature, the upper limbs are greatly enlarged and the lower ones dwarfed. Here again, the modification is for an obvious purpose, namely, the accomplishment of flight.

The modifications witnessed in limbs are invariably "means to ends." In the kangaroos and opossums it is not the upper or anterior extremities which are greatly developed, but the lower or posterior ones. These animals are designed to take prodigious leaps, and in order to effect this purpose, the tail, which is enormously increased in size, is called into requisition, and acts as a powerful spring in the leaping process. In the hare, and many quadrupeds, the posterior limbs are heavier than the anterior ones.

In many extinct animals, such as the colossal *Diplodocus carnegii*, Brontosaurus, Megatherium, and Iguanodon, several very perfect specimens of which latter I saw in the Museum at Brussels several years ago, the posterior extremities and tail are enormously developed, and form a tripod of support for the animals when feeding or sitting. In the giraffe the reverse holds good. In this beautiful animal, the neck and anterior extremities are greatly developed and elongated ; the posterior ones being stunted by comparison. In the auks and penguins the anterior extremities are stunted, the posterior ones being strong, and supporting the birds in a practically erect position. In all these cases, it is a question not of evolution, but of development in a particular direction and for a special purpose.

It would never occur to any one to regard the semi-erect position of the extinct and modern animals referred to, and the practically erect position of the auks and penguins, as constituting a valid claim to a close blood relationship with man, but this is exactly what is done by the evolutionists in the case of the anthropomorphous apes.

The enforced and artificial semi-erect position of the apes when standing or walking on all fours is regarded by evolutionists as conclusive proof that man is a lineal descendant of the ape. In reality, as I have shown, the position in question is a mere accident, and has no value in determining the rank of the apes as the ancestors of man. When a certain end is to be attained, the means are forthcoming. The organs are produced as original endowments. They do not grow spontaneously or of their own accord. Given the organs, they may improve by constant use, or they may deteriorate from non-use. The arm of the palsied man wastes and grows thin, that of the blacksmith becomes brawny and strong.

A sharp line of demarcation is to be drawn between the use and disuse of living structures. While use cannot produce a structure, disuse may partially or wholly destroy it. Fishes bred and living in dark caverns first lose their sight and then the organs of vision.

Parasites when they have attached themselves to living organisms capable of supplying them with all the nourishment they require drop their limbs and other parts of their bodies which were necessary to them when they led an independent existence. The parasites and the non-use of organs form admirable examples of *retrogression*. Retrogression, which is opposed to progression, bespeaks arrest of development, and even decay and dissolution. In retrogression *evolution* can play no part.

The erect position in man is not the result of evolution but of original endowment. His bones, joints, ligaments, fasciæ, aponeuroses, muscles, tendons, &c., are all specially modified to bring it about. The erect position is an attribute of his adult life, and to it he sooner or later attains. It is not the result of a compromise with other and more humble positions. It is his by birthright. It has been of untold advantage to him. It has liberated his upper limbs and hands for the performance of every conceivable kind of work. It has supplied his brain with instruments of incalculable value in all the affairs of life. When man is newly born he is helpless, and can neither stand, walk, nor run. In this he is inferior to many of the lower animals. A chick can run almost as soon as it leaves its shell, and many quadrupeds very quickly find their legs. It is otherwise with the genus *Homo*. In him everything is elaborate and slow. He has to learn to stand upright, and to walk and run. He is furnished with a finely modelled skeleton with beautiful joints, a powerful muscular system, and a highly sensitive nervous system, which very soon bring him into intimate relation with the outer world, and enable him to move about on the earth's surface with celerity and precision. The apparatus for assuming the erect position and for moving from place to place forms an integral and essential part of his being. It comes into operation in due time, and completes the edifice of the adult man.

Looking at man as we know him, it is evident we must regard him as a whole. If he eclipses all other animals

as to the wealth of his original endowment, it is because his development has proceeded further than that of any of his congeners.

The subject of development need not be gone into further than to say that "development" and "evolution" are not identical or convertible terms. A strong line of demarcation must be drawn between them. Evolution carries with it the idea of progress, and the manufacturing of one plant or animal out of another. Development does not always indicate unbroken advance. On the contrary, it means growth, or cessation of growth, in particular directions; it may even mean absorption and destruction of parts already formed. While plants and animals have apparently very simple and common beginnings, they develop along characteristic lines. The nature and amount of development make them what they are. They never become mixed up. Their individuality and identity are assured from the beginning. They never grow into anything other than themselves. A blade of grass does not develop into a palm, nor a mollusc into a crocodile. There are in the seed of the plant, and in the egg of the animal, the substance and the potential force which will, under natural and favouring conditions, ultimately produce the plant and animal each after its kind. It is beside the question to say, as evolutionists do, that the life histories of plants and animals are the life histories of all the plants and animals which preceded them. All that can be truly affirmed is that there is a general plan or scheme according to which plants and animals are built up. It is absurd to affirm that a man *in utero* is successively a fish, a reptile, and a bird, before he becomes a mammal.

A careful study of development completely negatives this view. Development does not proceed on general but on particular lines, and it is a distinguishing feature of development that it adds new parts here and retards the formation of new parts there, or fuses and destroys old parts. It is the case of the intelligent builder employing his material where it is required; due regard being had to the object in view both as regards structure and function. In architecture it is no uncommon thing to pull down as well as to build up, and this is exactly what nature does in the formation of organic beings—plant and animal alike.

While it is granted that there is a general plan in the formation of plants and animals, it cannot be denied that the plan admits of great variation in detail; the variation consisting of a major or minor amount of differentiation, the production or non-production of new parts, and the arrest or suppression of parts already formed.

It cannot be doubted that the seeds of plants and the eggs of animals fundamentally differ from each other at the outset, and that this original difference continues throughout the entire period of development. It is the reigning factor in plant and animal life. Still less can it be doubted that plants and animals are developed not on general but on particular and special lines. It is the finished or completed products with which we have ultimately to deal in estimating the exact position of plants and animals in the scheme of nature, and in every scheme of classification. The successive stages of development rather confuse than simplify the issue. The crux in the history of the development of every plant and animal is finality. Given finality, it is not difficult to determine what each plant and animal is. Without finality, or the completed whole to guide the judgment, the most serious mistakes may be committed. It is the final details of plants and animals which reveal the true nature of both, and until these details are discovered and fully appreciated, the secrets of organic nature must remain, practically, a sealed book.

Every part of every organic being comes under the influence of development; but development, as indicated, may proceed in one of three ways. It may proceed (*a*) by differentiation and the adding of new parts; (*b*) by the repression or absorption and destruction of previously formed parts; and (*c*) by the coalescence and union of several existing parts to form a strong whole. This is the case in the foot of the horse, and the wing of the bird, where certain of the digits are suppressed and fused for the purposes of locomotion.

DESIGN AS MANIFESTED IN THE HUMAN FOOT, HAND, AND ORGANS OF LOCOMOTION, &c.

The muscles of the foot and toes discharge complicated and far-reaching functions. As the reader will have perceived, these muscles are numerous, and run in almost every direction. To them are entrusted many of the important details of locomotion. They are adapted in the most remarkable manner to the longitudinal and transverse arches formed by the bones of the foot, and confer strength, mobility, and nicety of movement on the foot as a whole. A trained, educated foot can perform nearly all the functions, and with as much exactitude, as the hand itself. I remember, some years ago in Belgium, seeing in the great art gallery of Antwerp, an armless man copying pictures with his feet with as much ease, adroitness, and success as one possessed of the most perfect and highly trained hands. His work was truly exquisite, and could not be distinguished from pictures painted in the ordinary

way. Those who train their feet from necessity or choice can employ them as hands without difficulty. They can form beautiful characters in writing, and can eat with a knife and fork in quite a dainty manner.

It is with the foot as a travelling organ that I am chiefly concerned. It has warranty in its construction for the endurance displayed by it in the long wearisome journeys made by travellers in their double vocation of pioneers and discoverers. Thousands of miles are covered by it, and it is generally not the first part of the body to give out in strain and stress. It is, structurally speaking, enormously strong. It is composed of a large number of small bones, and these are strongly connected to each other by a powerful system of ligaments, which permit the bones to glide and move upon each other to only a very limited extent. The bones, moreover, as has been stated, are so arranged that they form a double arch—a longitudinal one, running in the direction of the length of the foot, and a transverse and more or less skew arch, which runs across the foot (Figs. 290 and 291).

The arch, as is well known in architecture and bridge-building, combines the maximum of strength with the minimum of material. It also lends itself to elegance of form, and there are few more beautiful objects in nature than a finely-turned ankle and a high instep, which are the characteristics of a handsome, well-made foot.

While the longitudinal and transverse arches of the foot secure the requisite elasticity and strength, the numerous ligaments of the bones of the foot provide the necessary degree of mobility. The nature of the mobility is remarkable. Only a very slight degree of movement is permitted between any two bones, but, the bones of the foot being comparatively numerous, the amount of movement in the foot, as a whole, is very considerable. It is a circumscribed movement in one sense, and a free movement in another. No other arrangement could have met all the requirements of the terminal organ of locomotion. The foot bristles with the most obvious design, just as the hand does, and nothing short of an intellectual First Cause could possibly have constructed it. "Evolution," "environment," and the modifications of untold ages would be quite unequal to this great task. The foot, like the hand, is no chance product. On the contrary, it is a specially created, contrived organ, the purpose of which was foreknown. It is a means to the most varied ends, and these ends were foreseen from the beginning. It was recognised that the animal to which the foot was vouchsafed must traverse the earth in search of food, and it was consequently as necessary to the existence of the animal as food itself.

§ 327. The Human Foot and Hand in Relation to the Foot of the Horse, and the Wing of the Bird, Bat, and Pterodactyl.

What is said of the foot is true of the lower extremity as a whole, likewise of every travelling organ, whatever its size, shape, and power — of the flippers of the sea mammal, the pectoral and caudal fins of fishes, the diving wings and swimming feet of birds, and the flying wings of insects, birds, bats, and reptiles. None of the travelling organs can be regarded as other than carefully planned, designed structures. No amount of ingenious argument can turn the edge of this statement. We might as well doubt our own existence as question its accuracy. Automatism, accident, and environment cannot produce the travelling organs of animals; neither can the animals themselves produce them by any process of willing and waiting. Even man with his godlike powers cannot add a cubit to his stature. There is but one explanation. They are provided as part of the original equipment of the animals possessing them, and form an absolutely necessary part of them. In making this statement I purposely omit any reference to so-called "natural selection." This phrase, seeing it ignores a First Cause, and seeing it does not itself claim to be either a first or a secondary cause, conveys to me no meaning.

To the muscles, bones, joints, and ligaments of the foot and hand are to be added the fasciæ, aponeuroses, fibrous sheaths, tendons, nerves, blood-vessels, lymphatics, &c., a wealth of material truly wonderful, and which cannot be accounted for by any purely mechanical origin apart from a Creator and intelligent First Cause. The extent and complexity of the arrangements in the foot and hand fly directly in the face, not only of "natural selection" but also of "evolution," unless evolution be regarded as another word for development—the extent and direction of the development being in every case predetermined.

Evolution is largely a synonym for differentiation and advance, and in the foot and hand of man it is carried to an extreme. Evolution, however, does not explain all, or nearly all, the facts of organic life, while development does. There is, in the histories of plants and animals, a backward as well as a forward swing of the pendulum. If evolution accounts for the forward movement it cannot possibly account for the backward movement. Development, arrest of development, fusion of existing parts, and development in particular directions, account for both. In no case is this seen to greater advantage than in the modifications of structure presented by the travelling organs of animals as a whole.

In man, and in a large number of quadrupeds, the foot displays five toes. This number of toes provides a

useful foot for walking, and, if webbed, for swimming. The five toes are the outcome of development and differentiation.

In the cloven hoofed animals (ox, sheep, goat, deer, &c.) the toes are reduced to two, and, in the solidungulate animals, such as the horse, ass, zebra, quagga, &c., they are reduced to one. The one-toed animals, in one sense, afford examples of arrest of development or retrogression ; in another sense, they supply instances of development and advance on particular lines. The one-toed animals cannot, strictly speaking, be regarded as evolutions or the outcome of structural advance ; and yet no one will venture to assert that the one-toed foot of the horse is not, everything considered, as perfect an organ of locomotion as the foot of a man. Evolution wholly fails here. The phenomenon can only be explained by original endowment, adaptation, and design. Everything in the universe is fitted to every other thing. There is a general plan which brings everything into line, whether the thing be living or dead, and the living and dead reciprocate and are complemental. The scheme of creation would otherwise break down.

The general plan, referred to, accounts for all the modifications witnessed in the travelling organs of animals, and for the so-called arrestments of developments, and the vestiges or remnants which ever and anon present themselves in the organic kingdom. It, however, becomes a question whether, teleologically speaking, there is any such thing as arrest of development. The one-toed horse and the two-toed ox are as perfect, in their way, as the three, four, or five-toed animals, judged from the locomotion standpoint. It cannot be said that the pectoral and caudal fins of the fish, where the rays greatly exceed five, are more perfect travelling organs, everything considered, than the foot of the horse : or that the wing of the bird, where the primary, secondary, and tertiary feathers are very numerous, is more effective in flying than the tail of the fish is in swimming. All that can be truly affirmed is that the travelling organs are, one and all, original structures specially devised to act on the earth, water, and air respectively ; these forming the fulcra or objectives of the travelling organs as a class, by means of which locomotion in its several ramifications is achieved. Whatever the nature, size, and shape of the animal, it must be equipped, independently and at the outset, with suitable travelling organs. To this there is no exception. The travelling organs are an original and essential part of all animals which move from place to place. What is true of the locomotor muscular system is true of all the other systems—the alimentary, excretory, respiratory, circulatory, nervous, &c. All the systems are original endowments or equipments. They are all necessary to the well-being and existence of the animal of which they form a part. The several systems are conferred on animals to enable them to cope successfully with everything within and without themselves. They are, in no case, chance products. On the contrary, animals are designed, completed wholes. If one animal be more complex than another it is because the Creator has so ruled it. If development proceeds further in one animal than in another, this affords no proof of inadequacy of structure, function, or creative power. Each animal is perfect within limits, and each is adapted to its environment or natural surroundings. The stages of development are as the rungs of a ladder. Some ladders have more rungs than others, but the ladder is perfect, according to its rungs, so far as they go.

Instead of regarding the travelling organs of animals as evolutions which carry with them the idea of differentiation and progress, it will be more correct to regard them as developments in particular directions ; these developments being complete, partial, or retrogressive in character, according to circumstances. The developments are arrested or retrogressive when they consist of fewer parts. Thus the wing of the bird, where the fingers are welded together and fused, is structurally less perfect and advanced than the wing of the bat, where the five digits are free. Similarly, the foot of the horse, which is composed of one digit, is structurally less perfect and advanced than the foot of the quadruped having five digits. When, however, it is pointed out that the fused finger bones of the bird's wing furnish a strong semi-rigid support for the highly elastic primary or rowing feathers of the pinion, it has to be recognised that no better arrangement could possibly be conceived for the wing cutting into, and supporting itself on, the thin evasive air. Similar remarks apply to the foot of the horse. It consists of one digit instead of five, but that one digit is greatly enlarged, strengthened, and furnished with a powerful hoof, which can be made to thunder against the hard earth without sustaining the slightest injury. The foot is the organ of support of the body—the lever which, coming in contact with the earth, urges the body forward in locomotion. In the horse it is the third digit which is greatly enlarged to form the foot ; the corresponding metacarpal or cannon bone having on either side of it two rudimentary metacarpal or splint bones (second and fourth). In the tapir, the third digit with its corresponding metacarpal bone is more than twice the size of the other digits. In the extinct flying reptile, the pterodactyl, the fifth digit is enormously enlarged as compared with the others, and supports the flying membrane ; the remaining digits taking no part. The enlargement of certain portions of the hands and feet for specific purposes is therefore not uncommon. This is especially the case in the pectoral fins of fishes, where the rays, which correspond with the digits in animals, are greatly increased. The enlargement of one

portion of a hand or foot is generally accompanied by a suppression, or partial suppression, of another portion (or portions).

In the wing of the bird and the foot of the horse there are strengthening, fusion, and dropping of fingers, but for very obvious ends. In terrestrial progression it is all important to diminish the size of the foot which comes in contact with the ground, provided the necessary strength, elasticity, and support are secured; the arrangement minimises friction. In flying, a diametrically opposite result must be secured. The wing must be expanded by means of its primary, secondary, and tertiary feathers to the utmost, so as to enable it to seize and entangle the tenuous, treacherous, rapidly escaping air. In the wing, support can only be obtained by a greatly expanded surface and a greatly increased degree of friction. The wing of the bird and the foot of the horse display in their structure and function the very essence of design. Each is developed and modified in a particular direction, but each culminates in the highest good when the object in view, in either case, is duly considered.

The true explanation of the wing of the bird and of the foot of the horse is to be found in original design, and in their power to perform particular kinds of work in a thoroughly scientific and effective way, apart from blundering and want of method. Original endowment is to be credited with the production of the wing, and of the foot of the horse, respectively. Both are expressly formed on acknowledged scientific principles, and these results cannot be achieved by chance, haphazard structures. The air cannot make the wing of a bird, nor the earth the foot of a horse, however long the period allowed for the manufacturing process. The wing and the foot are equally original creations.

Everything considered, it is safer to speak of the wing and the foot as special developments than as evolutions. Developments, as indicated, can be arrested at any point, or a bias given to secure development in a special direction and for a particular purpose. The back swing of the pendulum is possible in development, where arrest or retrogression can occur, but not in evolution, which necessarily carries with it the idea of differentiation and advance.[1]

The peculiarities of the limbs of the ox, horse, and bird are fully set forth in Plate cli.

PLATE CLI

Plate cli. illustrates the osseous arrangements of the limbs of the ox, horse, and bird. The typical number of digits in quadrupeds is five. In the ox they are reduced to two, and in the horse to one. In the bird there are four digits in the foot, but only three imperfect ones in the hand. The digits undergo a very remarkable modification in the limbs of the horse and in the wings of the bird to enable them to act as suitable levers for the ground and air respectively. In the horse one great digit (the third) supplants all the others. In the bird, the remains of three digits (the first, second, and third) can be traced, the chief being the second one. The second digit of the bird corresponds, more or less closely, to the third or surviving digit of the horse. In the bird, the wrist and carpometacarpal bones are somewhat mixed up, and the digits reduced in number, and fused.

In the extinct flying reptile, the pterodactyl, one greatly enlarged digit (the fifth) mainly supports the membrane forming the wing; the other four digits appearing as rudiments with claws. In the pterodactyl, as in the horse, one digit forms the organ of locomotion. It is otherwise in the modern bats, where the five digits take an equal share in supporting the flying membrane of the wing.

The modifications in the foot of the horse, the wing of the bird, the wing of the pterodactyl, and the wing of the bat afford admirable examples of design, and are worthy of very special attention.

Fig. 1.—The bones of the right foreleg of the ox (*Bos taurus*). Shows the cloven hoof and the two-toed arrangement of the foot characteristic of the animal. *a*, Scapula; *b*, spine of scapula; *c*, shoulder joint (ball and socket or universal in its nature); *d*, humerus or arm bone; *e*, elbow joint (grooved spiral hinge joint); *f*, olecranon which limits the extension movements of the forearm on the arm; *g*, ulna, and *h*, radius (forearm); *i*, wrist joint; *j*, large metacarpal; *j'*, small metacarpal (hand bones); *k*, large metacarpal bone grooved anteriorly and dividing into two at its lower portion; *l*, *m*, *n*, two separate digits with three bones each. These are, named from above downwards, the suffraginis, coronary, and pedal bones. The digits display beautiful grooved saddle-joints, which admit of free antero-posterior movement, but allow almost no lateral movement. The foot of the ox mainly differs from that of the horse at its lower portion, where it consists of *two* digits; the foot of the horse terminating in *one* digit.

Drawn from nature for the present work by C. Berjeau.

[1] The pedigree of the horse has been worked out more fully, perhaps, than that of any other mammal. It was taught by the older palæontologists that its ancestry, beginning with Palæotherium, passed through Anchitherium and Hipparion to the modern Equus; and it has come to be generally believed that the above forms are the direct ancestors of the horse. In the *Comptes Rendus*, however, M. Marcellin Boule points out that this view was abandoned by most palæontologists almost a quarter of a century ago. These fossil forms are to be regarded as dwindling terminations of two lateral branches rather than as in the direct line of Equus. And a similar fate has befallen the majority of ancestral forms which figure in the genealogical trees which have been constructed for other modern species. Sooner or later they are found not to possess the requisite characters for the part of ancestors, and must be looked upon as terminal offshoots from the main line. (From *St. Andrews Citizen* of June 23, 1906.)

PLATE CLI

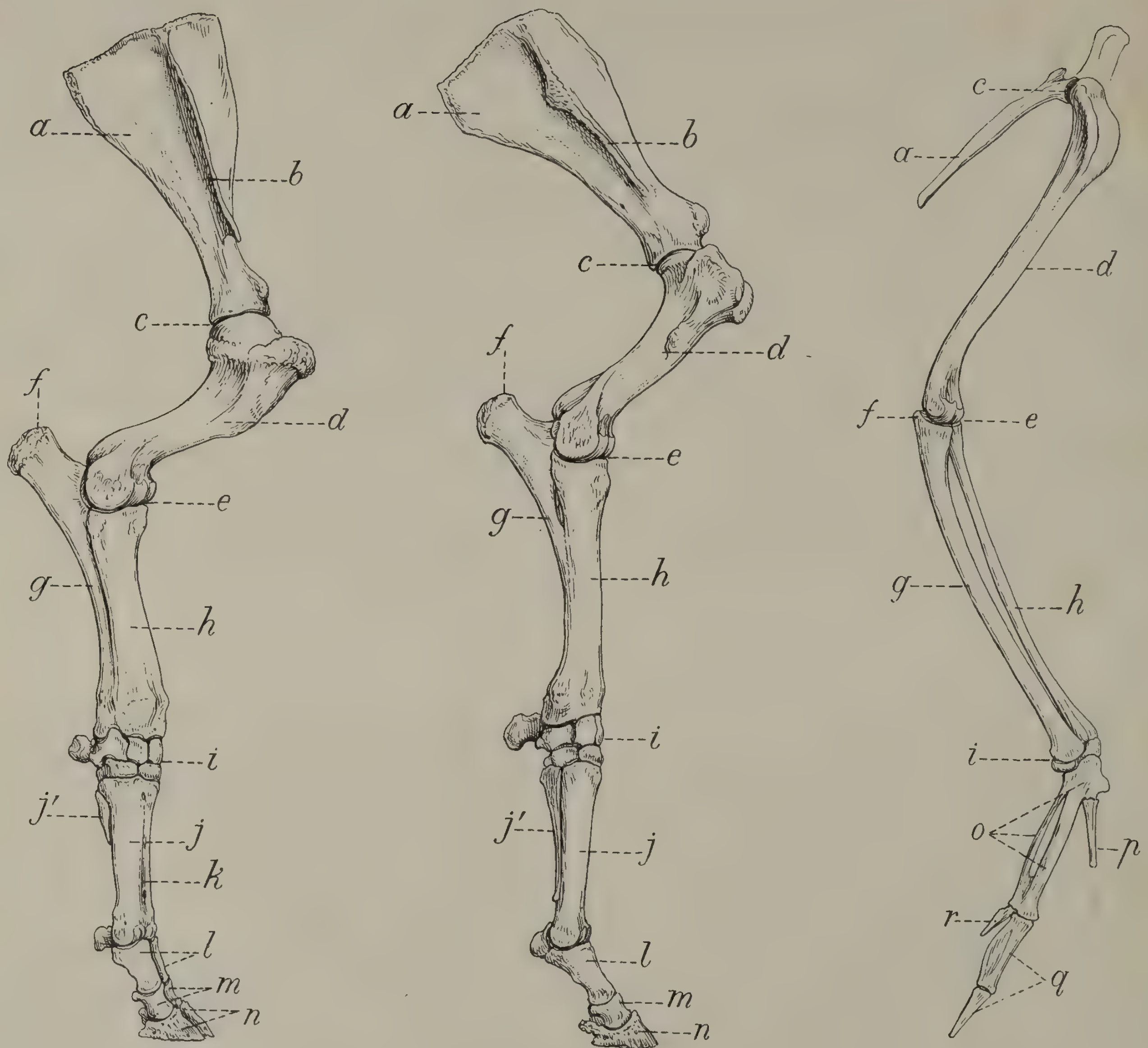


FIG. 1. FIG. 2. FIG. 3.

FIG. 2.—The bones of the right foreleg of the horse—Clydesdale or draught horse (*Equus caballus*). Shows the one-toed arrangement of the foot which separates the solidungulate animals from the cloven-hoofed ones. *a*, Scapula; *b*, spine of scapula; *c*, shoulder joint (universal or ball and socket); *d*, humerus or arm bone; *e*, elbow joint (grooved, spiral, hinge joint); *f*, olecranon which limits the extension movements of the forearm on the arm; *g*, ulna, and *h*, radius (forearm); *i*, wrist joint; *j*, large metacarpal or cannon bone, with two smaller, partially developed ones (one on either side, *j'*) imperfectly united to it by bony junction —these are known as lateral metacarpal or splint bones; *l*, *m*, *n*, largely developed single digit (third) consisting of suffraginis or upper portion of digit, coronary or middle portion, and pedal or lower portion armed with the hoof. The bones of the single digit reveal beautiful grooved, saddle-shaped joints, which admit of free antero-posterior movements but forbid lateral movements.
Drawn from nature for the present work by C. Berjeau.

FIG. 3.—The bones of the right wing of the whooper swan (*Cygnus musicus*). Shows remarkable modifications in the bones of the wrist and hand. In the former, the bones are reduced in number. In the latter, they are reduced in number and fused or run together to form a strong lever which terminates in a single digit (second) as in the horse, and which affords support to the great primary or rowing feathers of the wing which are mainly concerned in the production of flight. The bones of the hand of the bird and those of the horse have undergone the most extraordinary modifications in order to enable them to deal satisfactorily with the hard resisting earth on the one hand, and the mobile, highly elastic, non-resisting air, on the other. *a*, Scapula; *c*, shoulder joint (ball and socket or universal in character); *d*, humerus or arm bone; *e*, elbow joint (grooved, spiral, hinged joint); *f*, olecranon; *g*, ulna, and *h*, radius (forearm); *i*, wrist joint; *o*, carpo-metacarpal bones; *p*, first digit or thumb; *q*, second digit; *r*, third digit (bones of hand modified and fused).
Drawn from nature for the present work by C. Berjeau.

In Appendix I. of the present work I give original photographs of careful dissections by myself of the superior and inferior extremities of man: also directions as to how they are made. They are permanently preserved in Room I. of the Hunterian Museum of the Royal College of Surgeons of England (London), where they can be conveniently studied by those interested in the higher anatomy. The dissections, which are very minute, provide specimens of the arm, forearm, and hand; and of the pelvis, thigh, leg, and foot. Photographs and an account of other dissections by me are likewise given in Appendix I.

DESIGN AS DISPLAYED IN THE MUSCULAR SYSTEM GENERALLY

It would be difficult, if not indeed impossible, to find better examples of design than are furnished by the travelling organs of animals as a class. Even in the amœba, where there is no trace of structure, the movements of the protoplasm are evidently self-directed, and display a power within or without and behind this simplest of organisms. The same is true of all the modifications and structural differentiations in living matter through the whole organic series up to man. As the travelling organs become complex, so the power of moving and directing them increases as regards extent and exactitude. From the lowest to the highest, there is always the spontaneous directive agency. The movements of animals are never accidental and haphazard.

While the first place must be assigned to reproduction in the life histories of animals, the second is to be awarded to the organs of locomotion, whereby they are enabled to move about at will in the search for food, on which their existence ultimately depends. This fact invests the organs of locomotion with an importance all their own, and fully justifies the attempts made in the present work to systematise them, to reduce them to law and order from the physical side, and to show that they are designed structures.

In plants, and the lowest animals, fixity in certain localities is the outstanding feature of their existence. Everything they require is brought to them in the shape of air, heat, moisture, nutritive material, &c. They are provided by the great First Cause with environments which satisfy all their wants, and they live, in not a few instances, to extreme old age; some trees surviving for over 1000 years. In certain cases, the young of plants and animals, which, in the adult state, are invariably fixed, swim freely about until they find a suitable habitat, when they cast anchor and are fixed for life. In these cases, the temporary organs of locomotion are duly provided, and these organs are as scientifically constructed and perfect in their way as the travelling organs of the higher animals. They exhibit the same leading features, and are based on the same general principles. Whenever, and wherever, locomotion takes place, suitable provisions are made for it. The animal, to whatever genus or species it belongs, is provided with travelling structures which enable it to tread the earth's surface or to navigate the water or the air. The travelling organs, to whatever portion of the animal kingdom the animals belong, essentially resemble each other, and act on a common principle. In the higher animals they, for the most part, act as helices or screws, and produce double-curve figure-of-8 trajectories.

The modifications of the travelling organs of animals are apparently infinite, yet they are all referable to a common pattern on which a First Cause and design are writ large.

It is as easy for the Creator to supply animals with travelling organs which enable them to travel freely about and secure food as it is for Him to withhold travelling organs and supply food. Both conditions have their advantages, and both are designed conditions. In the one case, the food is made to invest the living thing; in the other, the living thing is made to invest and attack the food.

The more complex the individual the greater the necessity for travelling organs. As the animal rises in the scale of being, it requires a greater variety and amount of pabulum, and the necessity for suitable travelling organs becomes more and more pressing. The foot, the fin, and the wing are all brought into requisition, and no better examples of design can anywhere be found than are afforded by their wonderful modifications.

The foot, the fin, and the wing perform their marvellous movements by the aid of muscles situated on the body and in the extremities, and these muscles are all specially arranged and designed to move in concert to produce the double-curve figure-of-8 trajectories to which allusion has been made. The time devoted to a consideration of the muscular system, though considerable, cannot be regarded as lost when the immense importance of the subject of locomotion is taken into account. The organs of locomotion in the higher animals are, in some senses, as important as the organs of reproduction, and life without them would simply be impossible.

The extraordinary combinations of bones, joints, ligaments, fasciæ, tendons, muscles, nerves, blood-vessels, lymphatics, &c., which go to form the lower extremities or travelling organs of man reveal the highest conceivable skill, and cannot by any stretch of the imagination be regarded as haphazard, self-forming, self-regulating, self-

nourishing structures. They display a profound knowledge of mathematics and of the higher mechanics, and provide examples of adaptations to ulterior ends which only the Creator could devise.

There is nothing in environment which can explain even the most trifling peculiarities of the highly complex travelling organs in man and animals. They are original creations as much as or more than the environments themselves, and they are specially designed to act upon, utilise, and subdue the environments.

If environments could account for the existence of moving sarcode, which represents locomotion in its simplest form, which I cannot for a moment admit, they would altogether fail to account for the more complex muscles; still less would they account for the bones, joints, ligaments, tendons, fasciæ, blood-vessels, nerves, lymphatics, skin, hoofs, hairs, feathers, &c., found in the travelling organs of the higher animals. The travelling organs are not made by environment. The earth does not spontaneously produce the typical five-toed pedal organ, or the water the flipper, pectoral fin, swimming foot, and swimming tail: and, assuredly, the air does not form the delicate, elaborately constructed wing.

As a matter of fact, the travelling organs are formed for, and not by, their environment. They are carefully designed structures, and, in every instance, reveal a *means to ends* totally at variance with an automatic, mechanical origin. This should be self-evident to every one who reflects.

What is true of the organs of locomotion is, as already indicated, no less true of the organs of respiration, the circulatory apparatus, and the nervous system.

What form of environment could produce a pair of lungs, a heart of two or more cavities, and a cerebro-spinal nervous system? Granted the lungs and heart were produced mechanically—how are they to be set going and kept going with a steady rhythm during the life of the individual? What is to supply the complex regulating nervous system?

Other systems have to be accounted for; the osseous system with its wonderful joints and ligaments; the vascular system with its interminable branches; the lacteal system revealing a perfect labyrinth of the most delicate vessels; the glandular system with its power of producing from the blood a secretion at one point, and returning it to the blood at another point, or even of casting it out of the system as a waste product.

What form of environment could possibly produce such widely different systems and organs? There is only one explanation. All are the outcome of design—all are the product of an intelligent First Cause.

As already stated, it is not a case of environment producing the systems and organs, nor of the systems and organs producing the environment, but of the Creator producing both.

The muscular arrangements in man are the outcome of design in a marked degree. The muscles, as has been explained, are very numerous, and work together and consentaneously in groups and to given ends. They form a complemental designed system. They work within certain limits which are predetermined. They are formed before they are required, and in anticipation of the function they are ultimately called upon to discharge. They are developed from within and not from without. They are not, and never can be, the products of environment or external conditions. They are in no sense accidental structures. They spring into being sometimes consecutively and sometimes simultaneously, as required, and form, even *in utero*, a carefully designed system. They make their appearance with the other parts of the body long before the subject of locomotion presents itself. Walking and running are not included in the uterine movements—nevertheless the muscles are developed in anticipation of a free terrestrial existence. This bespeaks design and prescience of the highest order. The muscles during the development of the fœtus spread over the body in every direction. They are the prime movers of every part of the body. They have formed for them *in utero*, as auxiliaries or adjuncts, an elaborate, cunningly contrived osseous or bony system with numerous exquisitely constructed joints—the muscles, bones, and joints being, for the most part, spiral in their nature. The bones supply the levers on which the muscles act, and the muscles and levers can confine their movements to the body itself, or they can extend them to *terra firma*, as in walking, running, jumping, &c. The muscular and osseous systems are developed *pari passu* prior to birth. Neither are required before that event. This of itself forms an unanswerable argument in favour of design and an Intelligent Designer. The end to be secured is seen from the beginning. Everything is reasoned out and predetermined. The muscular and bony systems are provided in anticipation of the period when both will be necessary to secure food for the continuation of the race. Reproduction would avail nothing if the power of locomotion were withheld.

The animal is not a patchwork composed of tardy instalments; it is a designed organism, perfect and plenary from the beginning. Animals vary as to their complexity or degree of differentiation, but each is adequate for the requirements of existence from the outset. The higher and lower plants and animals reciprocate within limits, but the higher and highest animals are in no sense dependent for their birth and being on the lower and lowest animals. The animal series is a graduated one, but each is separate and independent at its inception and subsequently. The different members of the series form an ascending system, but each discharges its appointed duties,

and so fulfils the object for which it was called into existence. The lower members of the animal community (and this is true also of plants) contribute to the well-being of the members of the higher community in the matter of food and other important respects, but this affords no proof that the higher plants and animals are manufactured or evolved from the lower ones. It only goes to show that creation, and the intelligence and design which it displays, is a perfected system, adequate and plenary from the first and for all time. In this we have an explanation of the existence and persistence of type.

The Creator fashioned both the inorganic and organic kingdoms. He made the plant and animal from the elements of the inorganic or dead kingdom, but in so doing He superadded the subtle, mysterious principle of life, which separates by an impassable gulf the organic from the inorganic kingdom. The Creator is the Designer and Upholder of both kingdoms, and traces of His handiwork everywhere appear. The two kingdoms are complemental, and adapted to each other; they are in no sense opposed to each other. The plant and animal are adapted to their surroundings or environment, and the environment is, in turn, subordinated to the requirements of the plant and animal. Environment in no case makes or modifies the plant or animal to any very appreciable extent.

It is a complete reversal of the order of nature to regard environment as a leading factor in the production of plants and animals now or at any period of their life histories.

Life was from the first superior to environment; and the latter performs quite an unimportant rôle in the great scheme of the universe.

I am well aware that there are those who maintain that every part of the inorganic kingdom is living, and that no real distinction can be drawn in this respect between the inorganic and the organic kingdoms. Some even go the length of asserting that the molecules of the inorganic kingdom are possessed of consciousness, memory, and souls.

The quasi-philosophers who advocate those views indulge in the reprehensible practice of altering the form and meaning of words well known and understood. Their practice is an insidious and dangerous one, and calculated to mix up issues which are essentially and fundamentally distinct. By substituting specious words and phrases for things well known and accepted by even ordinary readers, incalculable damage is done to science, to say nothing of truth. As a case in point, the phrase "natural selection," which in Mr. Darwin's time was strictly confined to living things, is now applied to inorganic dead things. One naturally inquires where natural selection comes in, either in the inorganic or organic kingdoms? Selection implies a selector, and the selector must be outside the things themselves, for, as I have explained elsewhere, the things cannot select and perpetuate their good properties to the exclusion of their bad and undesirable ones. Selection, in every case, involves the exercise of intelligence. It is not an accidental or blind act. If natural selection means anything it means "God-selection." Natural selection as employed by Mr. Darwin and his followers cannot be regarded as a cause. It, in reality, explains nothing. While Mr. Darwin, and those who think with him, ignore a First Cause in the origin of species by means of natural selection they cannot demonstrate the operation of even an erratic, fitful, secondary cause.

Mr. Herbert Spencer was one of the first to discover and expose the inadequacy of Mr. Darwin's famous phrase, and supplemented it with a phrase of his own, namely, "the survival of the fittest." Mr. Spencer, however, soon perceived the insufficiency of his own phrase, discarded it, and invented new ones to act as balustrades. The new phrases have been found to be quite as unsatisfactory as their predecessors—they are all "make believes" in character. Mere words, however plausible and cunningly combined, cannot establish a principle or make true what is essentially false. This is a fact which cannot be too widely recognised. "Phrase-making," it should be stated, has latterly become a fashionable occupation, and when those hungering after knowledge ask for a substantial meal, they are treated to what is practically a pretentious feast of empty husks.

The phrase-makers—and they are numerous—seek to break down well-defined boundaries in a covert way, and to set up in their stead a lax nomenclature and loose modes of reasoning which set law and order at defiance.

The abuse of language on the part of certain physicists, monists, and biologists, is becoming a scientific scandal, and can only result in "confusion worse confounded."

When theorists divorce language from its original and universally accepted meaning, and take refuge in vague, carefully manufactured phrases, it is the bounden duty of all lovers of truth to make a resolute stand. If the insidious sapping of the foundations of science be not vigorously resisted, a time will come when the wrong will be made to appear the right, and the Creator will be ousted and excluded from His own universe.

The denial of design in the universe is the thin end of a wedge, which, if driven home, will rob creation of its chief glory. It will elevate the creature above the Creator, and its goal will be atheism and irreligion of a debasing type. The glorification of man, and the intelligence of man, will form poor substitutes for the eternal verities in which the greatest and best thinkers unflinchingly believe. (See footnote to p. 696 from Professor G. H. Darwin's South African Address, 15th August 1905.)

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